Ground water

By : Prof. Fathy H. Mohamed

Importance of Underground Water

- Groundwater occurs not only in underground "rivers‟, but also in countless tiny **pore spaces** between grains of soil and sediment, plus narrow joints and fractures in bedrock.
- Table 11.1 contains estimates of the distribution of fresh water in the hydrosphere. Clearly the largest volume occurs as glacial ice. Second in rank is ground water, with slightly more than 14 percent of the total. However, when ice is excluded and just liquid water is considered, more than 94 percent of all fresh water is groundwater.

Table 11.1 Fresh Water of the Hydrosphere

Parts of the Hydrosphere	Volume of Freshwater (km^3)	Share of Total Volume of Freshwater (percent)	Rate of Water Exchange
Ice sheets and glaciers	24,000,000	84.945	8000 years
Groundwater	4,000,000	14.158	280 years
Lakes and reservoirs	155,000	0.549	7 years
Soil moisture	83,000	0.294	1 year
Water vapor in the atmosphere	14,000	0.049	9.9 days
River water	1,200	0.004	11.3 days
Total	28,253,200	100.000	

SOURCE: U.S. Geological Survey Water Supply Paper 2220, 1987

Importance of Underground Water

- Geologically, goundwater is important as an erosional agent. The dissolving action of groundwater slowly removes soluble rock such as limestone, allowing surface depressions known as **sinkholes** to form as well as creating subterranean caverns.
- The rate of exchange for groundwater is 280 years. This figure represents the amount of time required to replace the water now stored underground. By contrast, the rate of water exchange for rivers is just slightly more than 11 days: If the groundwater supply to a river were cut off and no rain fell, the river would run dry in just over 11 days.
- Thus, when we see water flowing in a river during a dry period, it represents rain that fell at some earlier time and was stored underground.

Distribution of Underground Water

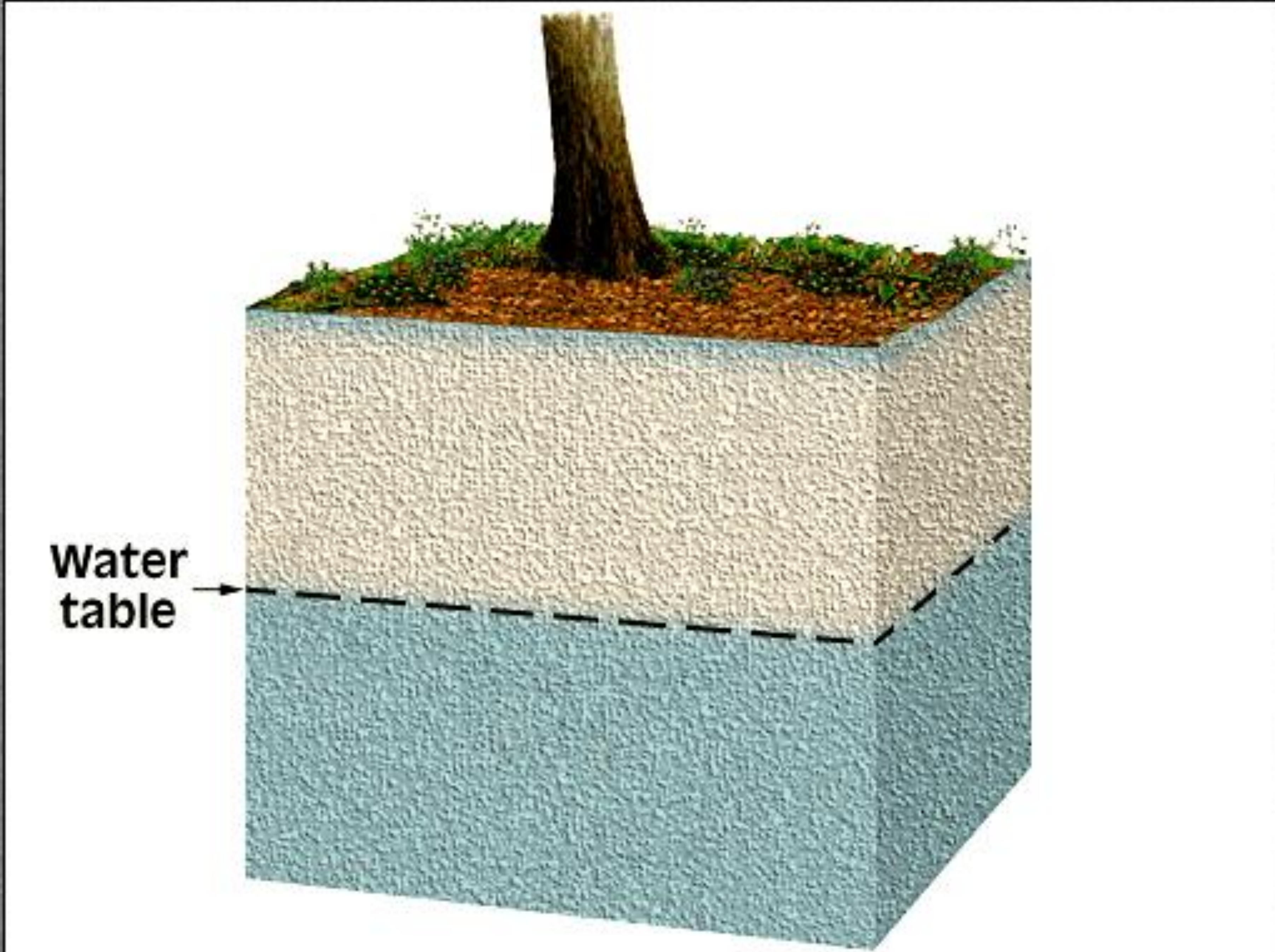
- Heavy rains falling on steep slopes underlain by impervious materials will obviously result in a high percentage of the water running off. Conversely, if rain falls steadily and gently upon more gradual slopes composed of materials that are easily penetrated by the water, a much larger percentage of water soaks into the ground.
- Water that is not held in this **belt of soil moisture** penetrates downward until it reaches a zone where all of the open spaces in sediment and rock are completely filled with water. This is the **zone of saturation**. Water within it is called **groundwater**.

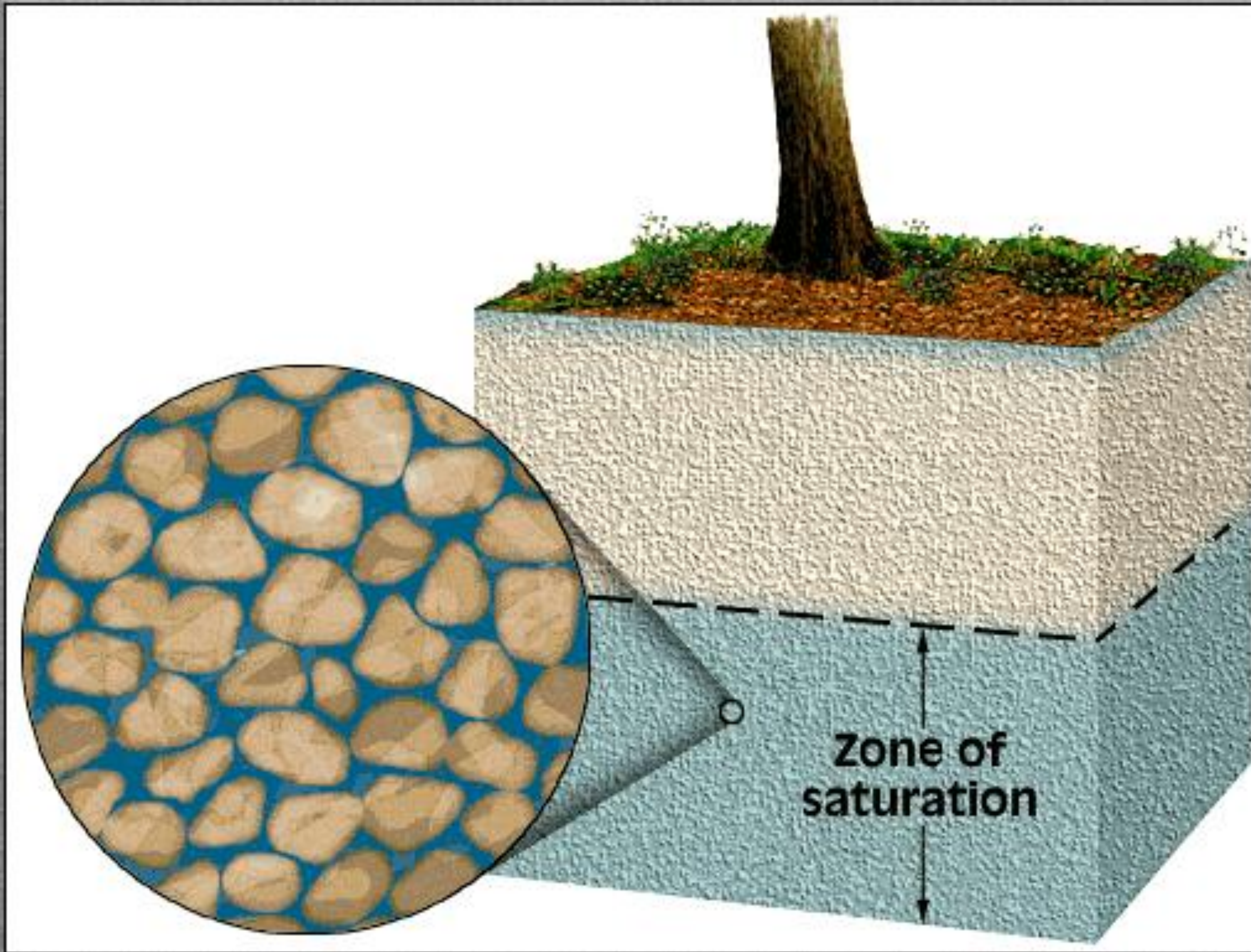
Distribution of Underground Water

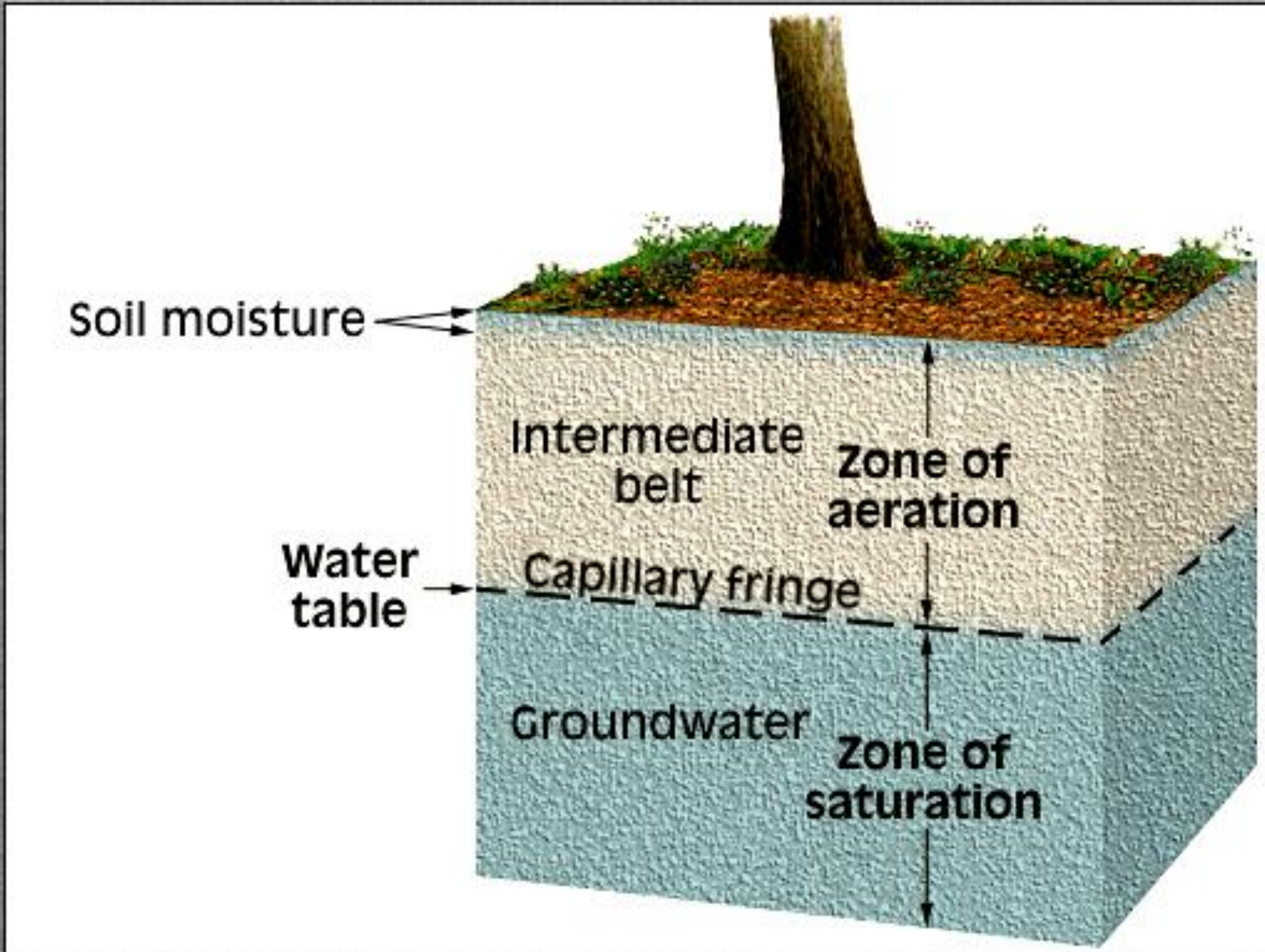
- The upper limit of this zone is known as the **water table.** Extending upward from the water table is the **capillary fringe.** Here groundwater is held by surface tension in tiny passages between grains of soil or sediment. The area above the water table that includes the capillary fringe and the belt of soil moisture is called the **zone of aeration.** The open spaces are unsaturated and filled mainly with air.

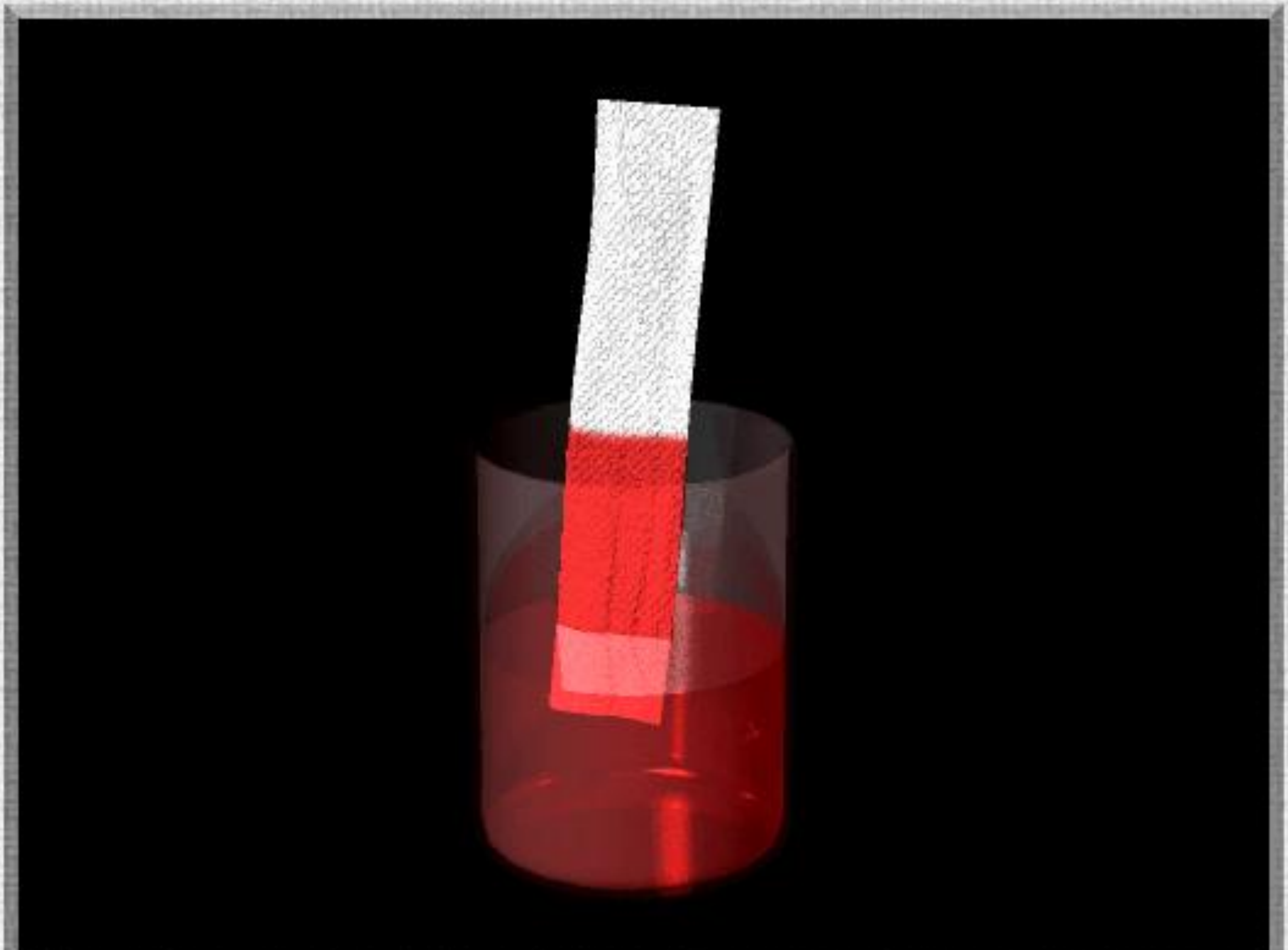
- **The Water Table**

- Although we cannot observe the water table directly, its elevation can be mapped and studied in detail where wells are numerous because the water level in wells coincides with the water table.

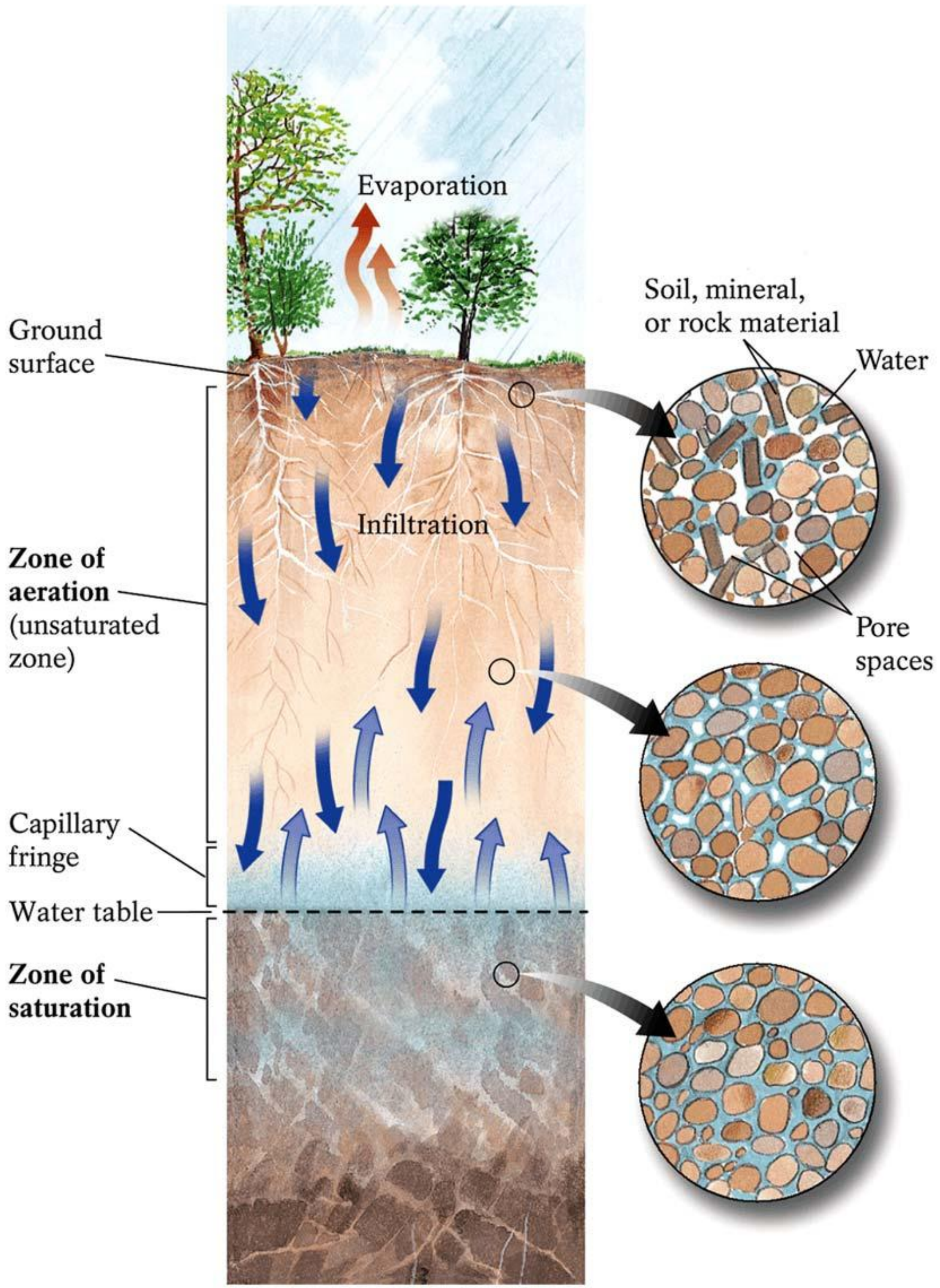

Water
table


Zone of
saturation

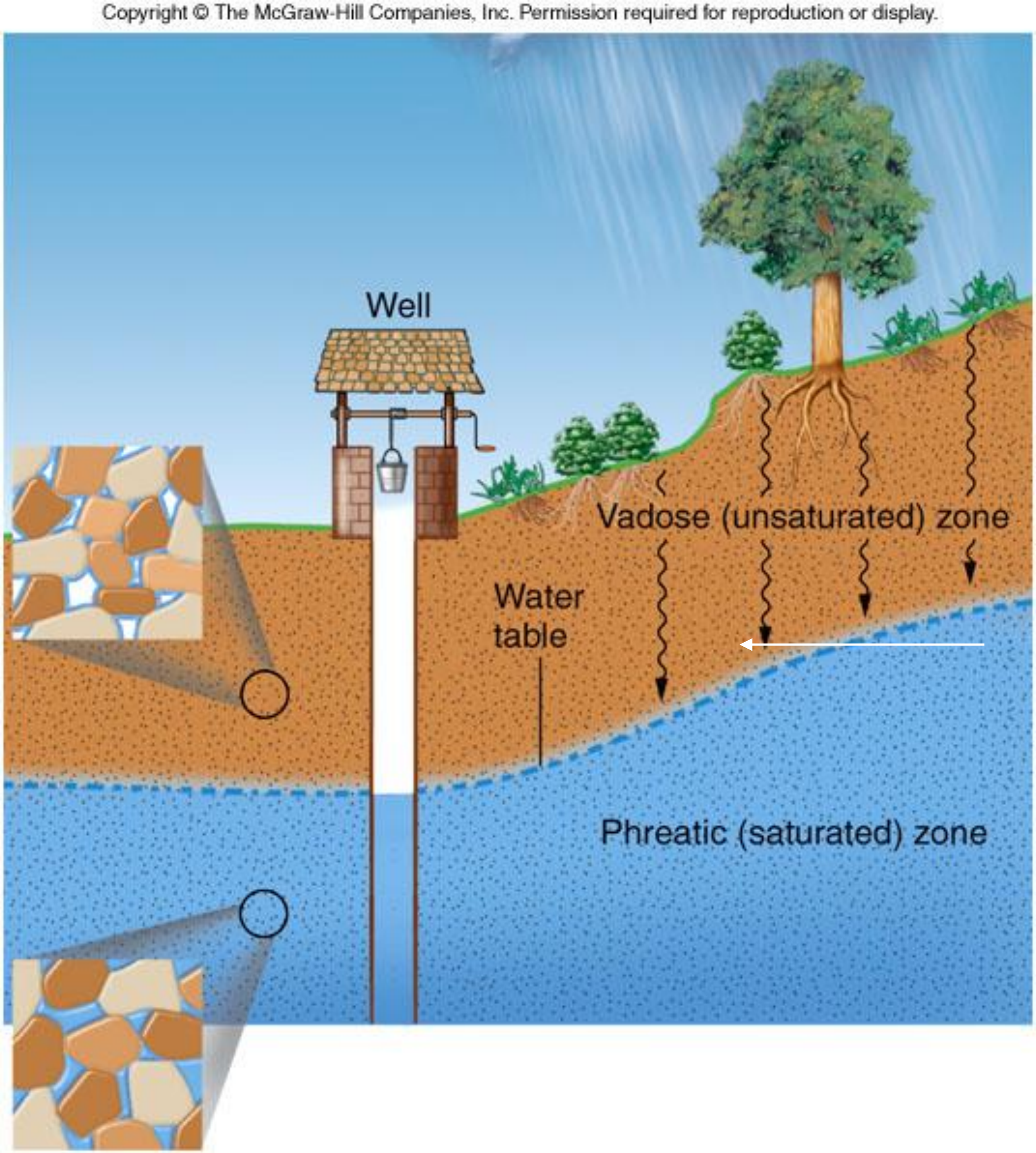

Soil moisture
Intermediate belt
Zone of aeration
Water table
Capillary fringe
Groundwater
Zone of saturation



Water Table


Evaporation
Ground surface
Infiltration
Zone of aeration (unsaturated zone)
Capillary fringe
Water table
Zone of saturation
Soil, mineral, or rock material
Water
Pore spaces

Water Table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Well
Vadose (unsaturated) zone
Water table
Phreatic (saturated) zone

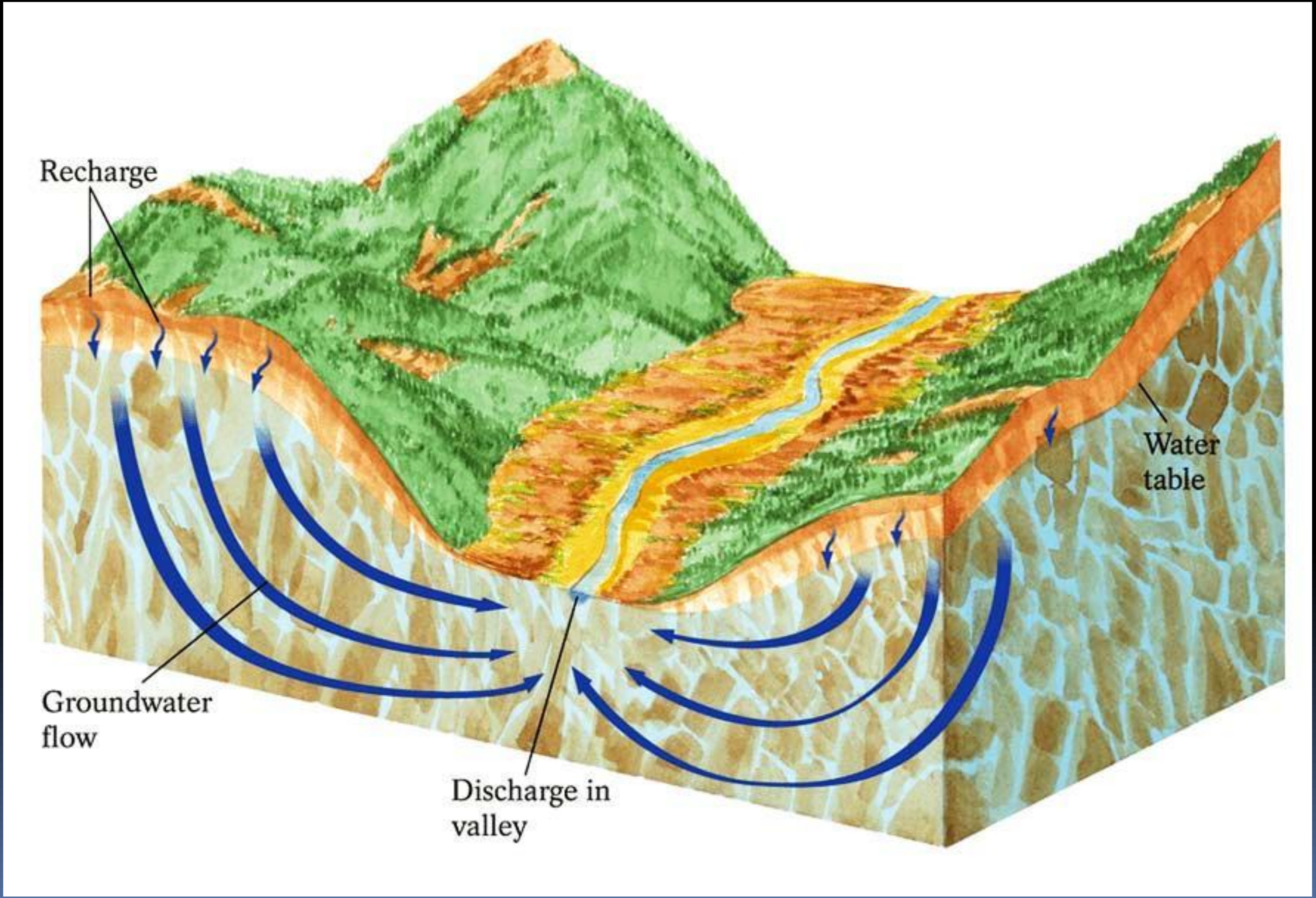
The Water Table

- Such maps reveal that the water table is rarely level, as we might expect a table to be. Instead, its shape is usually a subdued replica of the surface topography, reaching its highest elevations beneath hills and then descending toward valleys. Where a wetland (**swamp**) is encountered, the water table is right at the surface. Lakes and streams generally occupy areas low enough that the water table is above the land surface.
- Several factors contribute to the irregular surface of the water table. The most important cause is that groundwater moves very slowly and at varying rates under different conditions. Because of this, water tends to "pile up" beneath high areas between stream valleys.

The Water Table

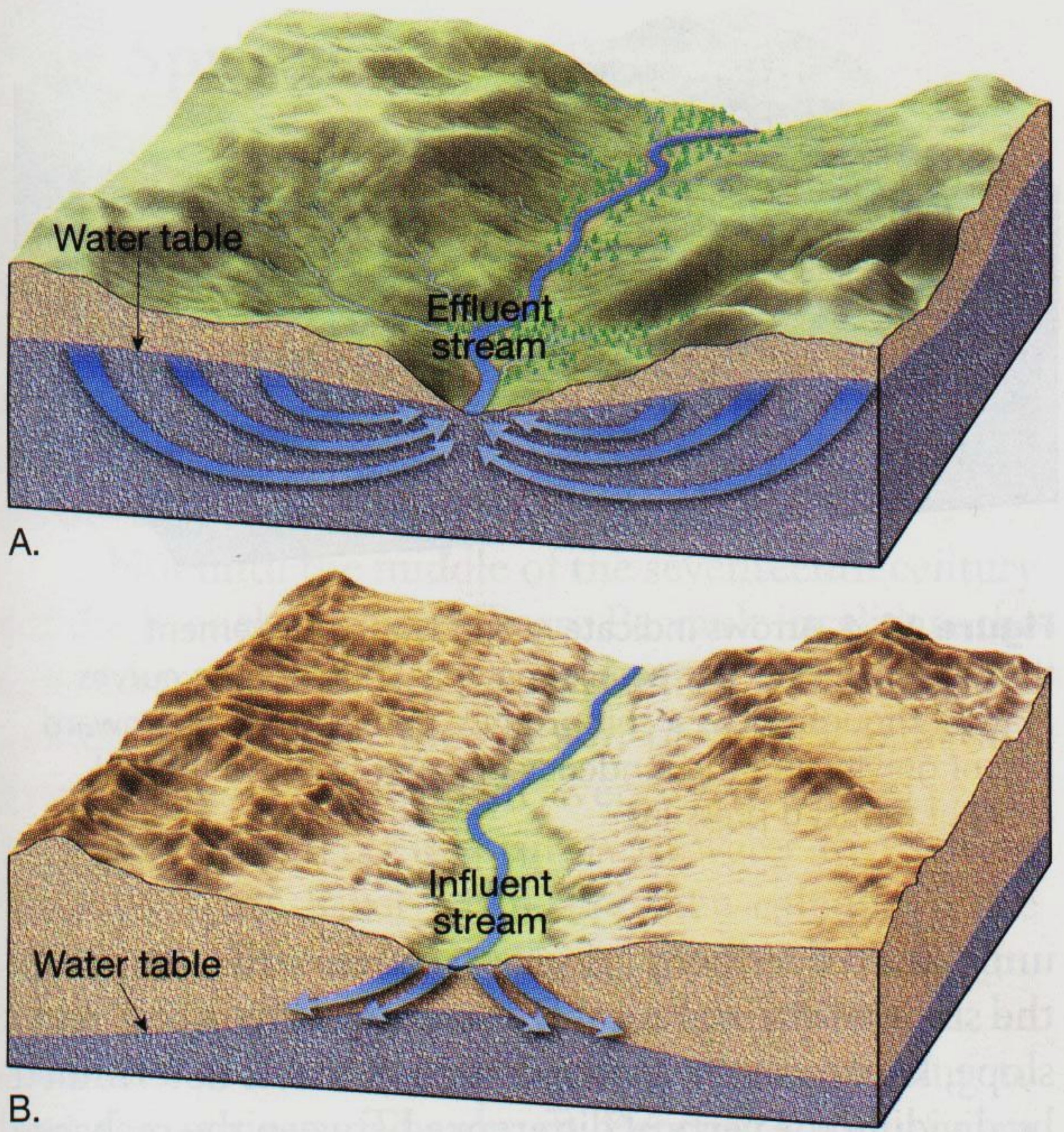
- If rainfall were to cease completely, these water table "hills" would slowly subside and gradually approach the level of the valleys.
- Other causes for the uneven water table are variations in rainfall and permeability from place to place.
- The relationship between the water table and a stream in a humid region is illustrated in Figure 11.3A. Even during dry periods, the movement of groundwater into the channel maintains a flow in the stream. In situations such as this, streams are said to be **effluent**.

Water Table and Surface Topography



The Water Table

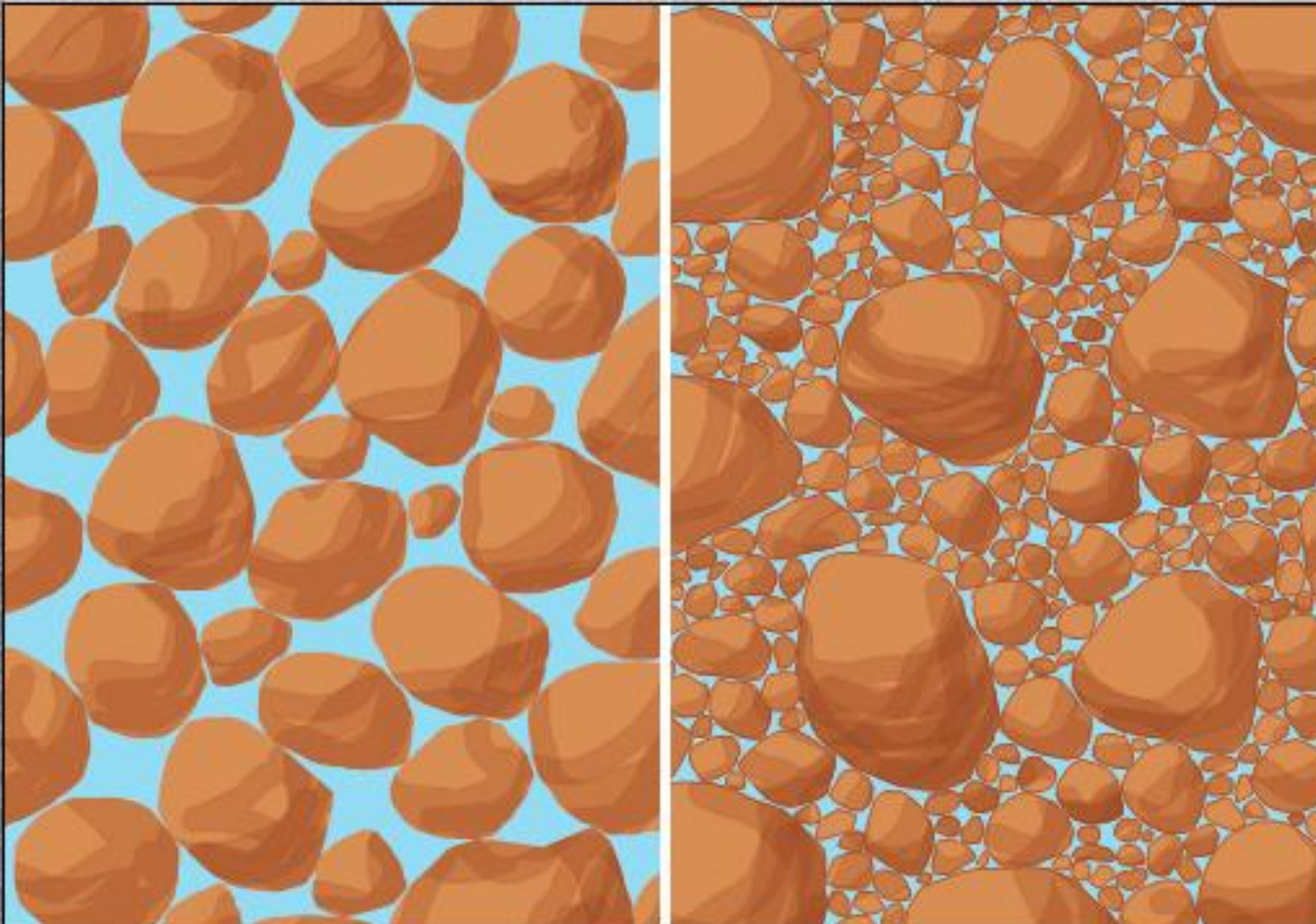
- By contrast, in arid regions, where the water table is far below the surface, groundwater cannot contribute to stream flow. Therefore, the only permanent streams in such areas are those that originate in wet regions and then happen to traverse the desert. (Examples are the Nile River in Egypt.
- Under these conditions the zone of saturation beneath the valley floor is supplied by downward seepage from the stream channel, which, in turn, produces an upward bulge in the water table. Streams that provide water to the water table in this manner are called **influent streams**.



Effluent streams are characteristic of humid areas.
B. Influent streams are found in deserts.

Factors Influencing the Storage and Movement of Groundwater

- Two factors are especially important—porosity and permeability.
- **Porosity**
- Water soaks into the ground because bedrock, sediment, and soil contain countless voids or openings called pore spaces.
- The quantity of groundwater that can be stored depends on the **porosity** of the material, which is the percentage of the total volume of rock or sediment that consists of pore spaces.



Well-sorted = higher porosity Poorly sorted = lower porosity

Factors Influencing the Storage and Movement of Groundwater

- Voids most often are spaces between sedimentary particles, but also common are joints, faults, cavities formed by the dissolving of soluble rock such as limestone.
- Variations in porosity can be great. Sediment is commonly quite porous, and open spaces may occupy 10 to 50 percent of the sediment's total volume. Pore space depends on the size and shape of the grains, how they are packed together, the degree of sorting, and in sedimentary rocks, the amount of cementing material. For example, clay may have a porosity as high as 50 percent, whereas some gravels may have only 20 percent voids.

Factors Influencing the Storage and Movement of Groundwater

- Where sediments of various sizes are mixed, the porosity is reduced because the finer particles tend to fill the openings among the larger grains. Most igneous and metamorphic rocks, as well as some sedimentary rocks, are composed of tightly interlocking crystals so the voids between the grains may be negligible. In these rocks, fractures must provide the voids.

Permeability, Aquitards, and Aquifers

- Porosity alone cannot measure a material's capacity to yield groundwater.

Factors Influencing the Storage and Movement of Groundwater

- Rock or sediment may be very porous yet, still not allow water to move through it. The pores must be ***connected*** *to* allow water flow, and they must be ***large enough*** to allow flow. Thus, the **permeability** of a material, its ability to ***transmit*** a fluid,is also very important.
- The smaller the pore spaces, the slower the water moves. Here groundwater is divided into two-categories: (1) that portion which will drain under the influence of gravity (called ***specific yield***) and (2) that part which is retained as a film on particle and rock surfaces and in tiny openings (called ***specific retention****).*

The tiny pore spaces between clay particles mean very low permeability.

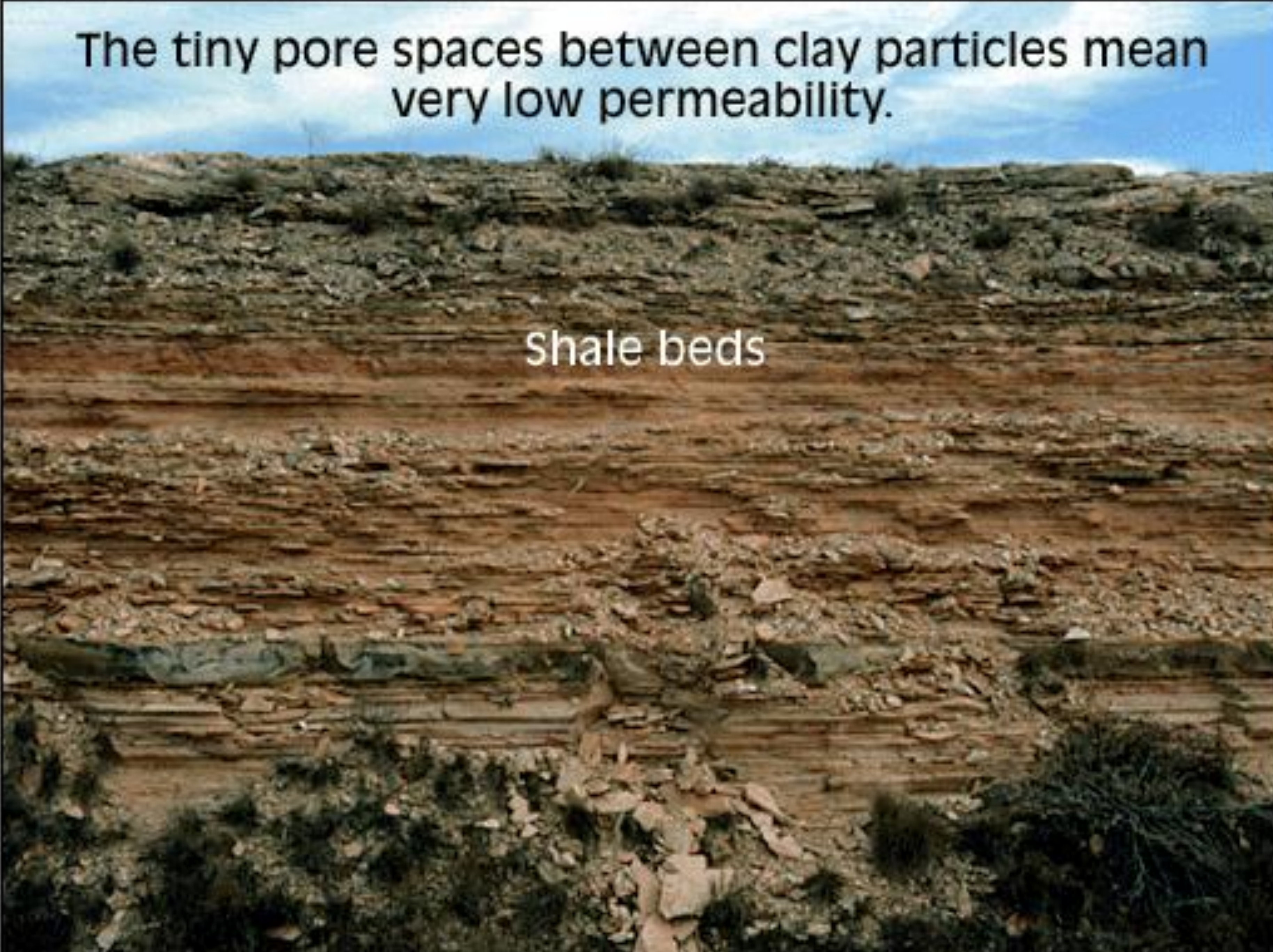


Table 11.2 Selected Values of Porosity, Specific Yield, and Specific Retention*

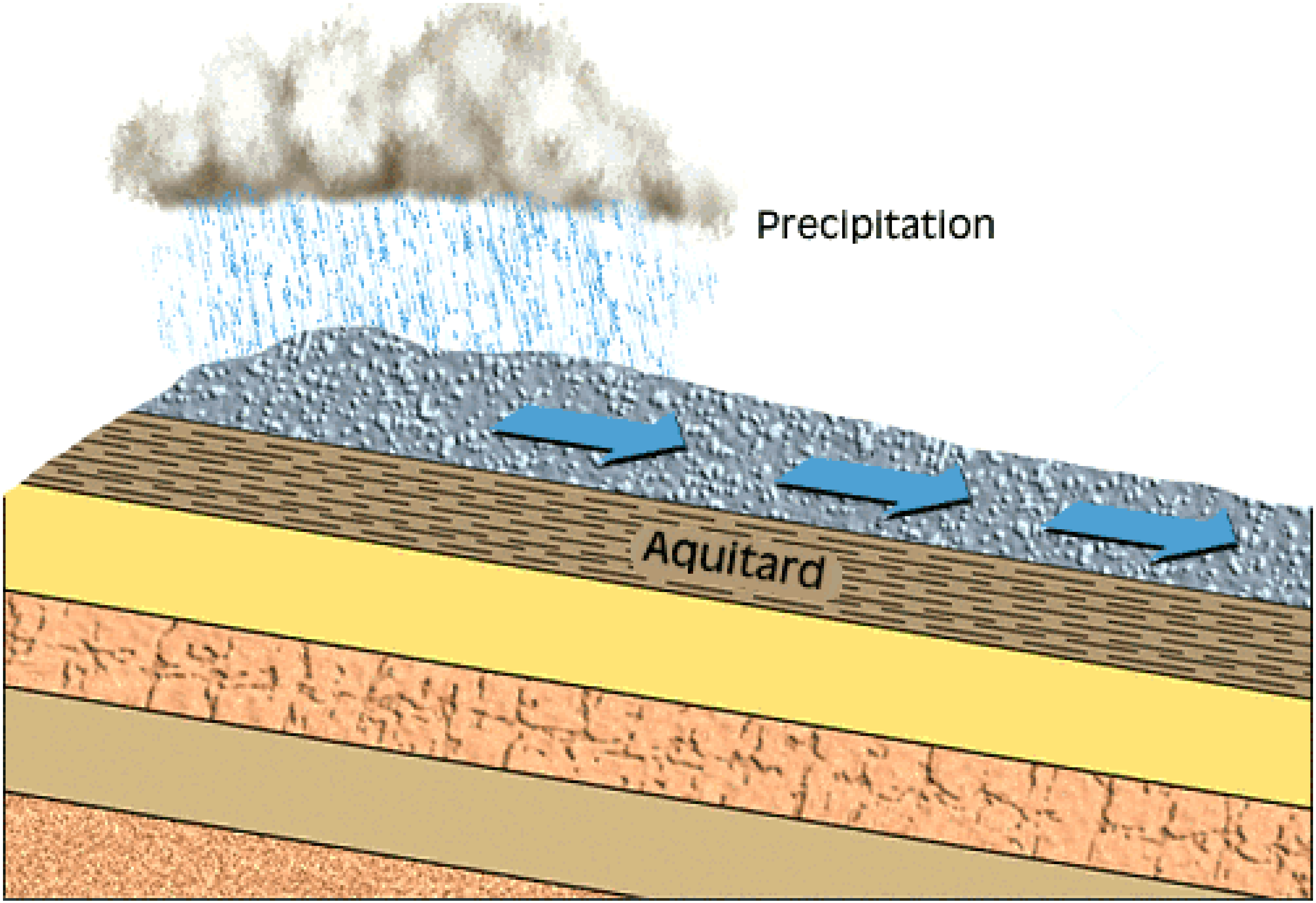
Material	Porosity	Specific Yield	Specific Retention
Soil	55	40	15
Clay	50	2	48
Sand	25	22	3
Gravel	20	19	1
Limestone	20	18	2
Sandstone (semiconsolidated)	11	6	5
Granite	0.1	0.09	0.01
Basalt (fresh)	11	8	3

*Values in percent by volume

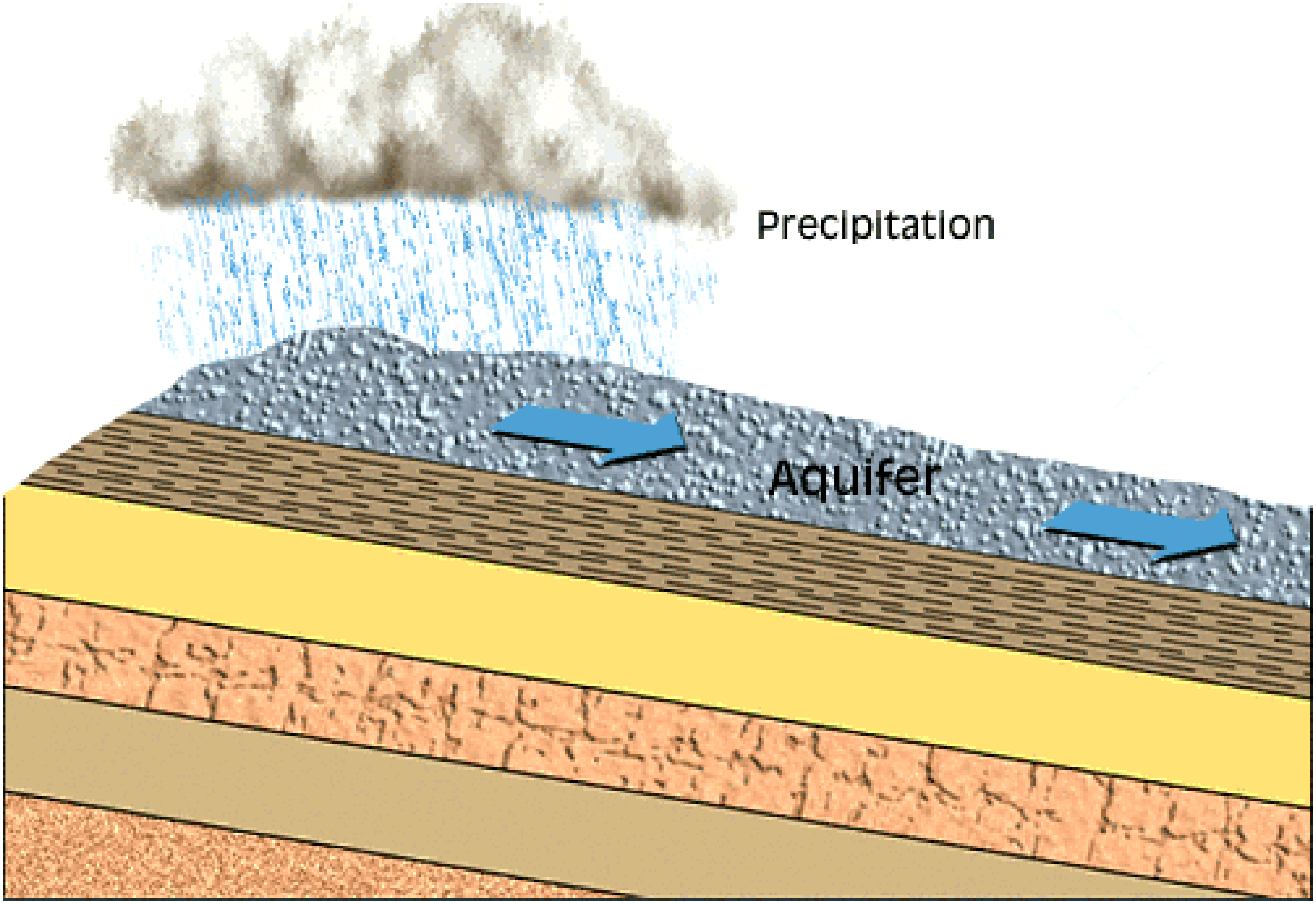
SOURCE: U.S. Geological Survey Water Supply Paper 2220, 1987

Factors Influencing the Storage and Movement of Groundwater

- Specific yield indicates how much water is actually available for use, whereas specific retention indicates how much water remains bound in the material. For example, clay's ability to store water is great owing to its high porosity, but its pore spaces are so small that water is unable to move through it. Thus, clay's porosity is high but because its permeability is poor, clay has a very low specific yield.
- Impermeable layers that hinder or prevent water movement are termed **aquitards.** Clay is a good example. On the other hand, larger particles, such as sand or gravel, have larger pore spaces. Therefore, the water moves with relative ease. Permeable rock strata or sediment that transmit groundwater freely are called **aquifers.** Sands and gravels are common examples.



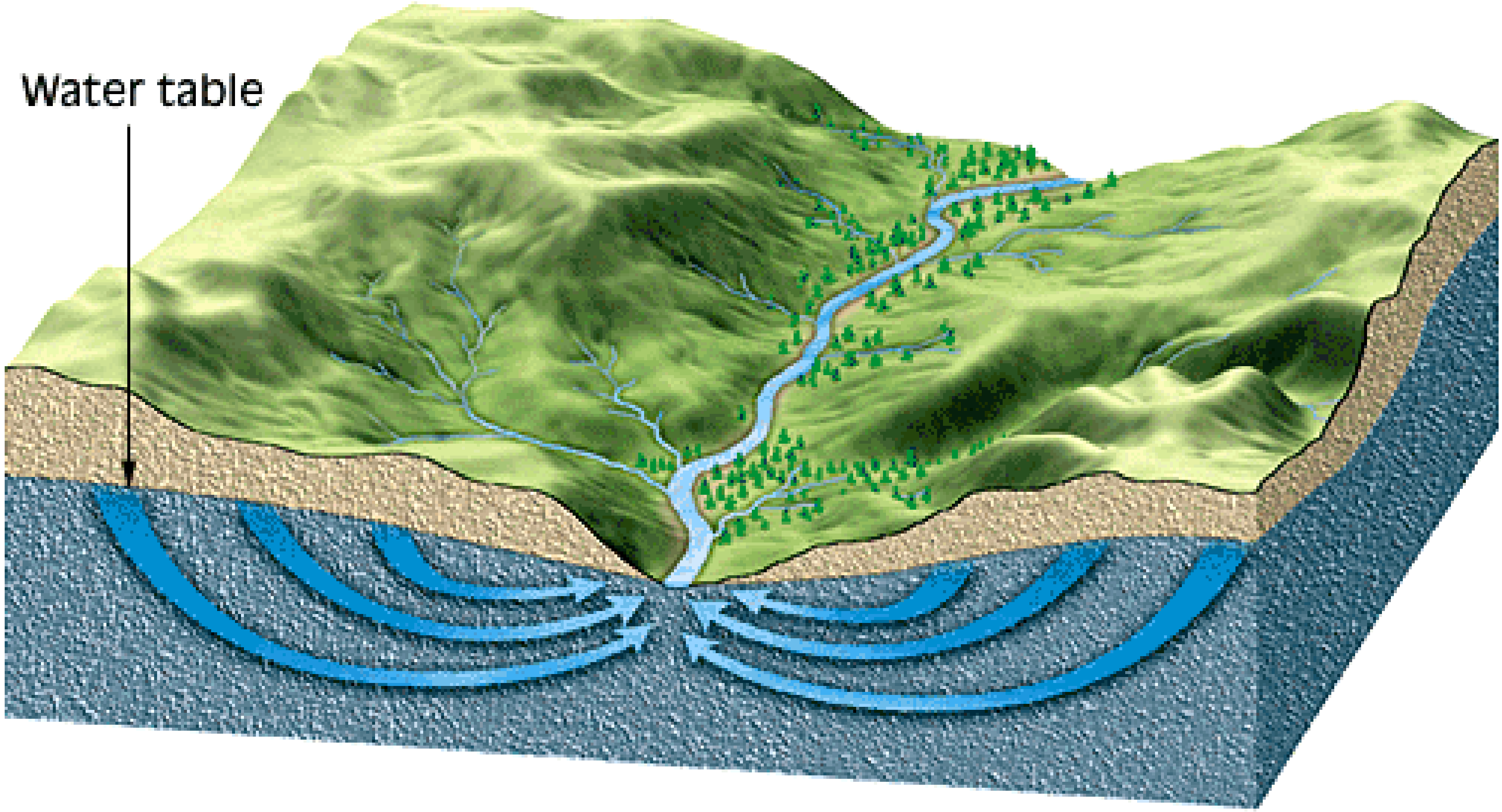
Aquitard – hinders or prevents groundwater movement.



Aquifer – readily transmits groundwater.

Movement of Groundwater

- Much of the water follows long curving paths toward the zone of discharge.
- The Figure shows how water percolates into a stream from all possible directions. Some paths actually turn upward, apparently against the force of gravity, and enter through the bottom of the channel. This is easily explained: The deeper you go into the zone of saturation, the greater is the water pressure. Thus, the looping curves followed by water in the saturated zone may be thought of as a compromise between the down ward pull of gravity and the tendency of water to move toward areas of reduced pressure.
- The modern concepts of groundwater movement were formulated by Henry Darcy, a French engineer. Darcy found that if permeability remains uniform, the velocity of groundwater will increase as the slope of the water table increases.


Water table

Movement of Groundwater

- The water table slope, known as the **hydraulic gradient**, is determined by dividing the vertical difference between the recharge and discharge points (a quantity known as the **head**) by the length of flow between these points. **Darcy's Law** can be expressed by the following formula:
  - $V=K. h/l$
- where *V* represents velocity, *h* the head, *l* the length of flow, and *K* a coefficient that accounts for a material's permeability.

Calculation of hydraulic gradient

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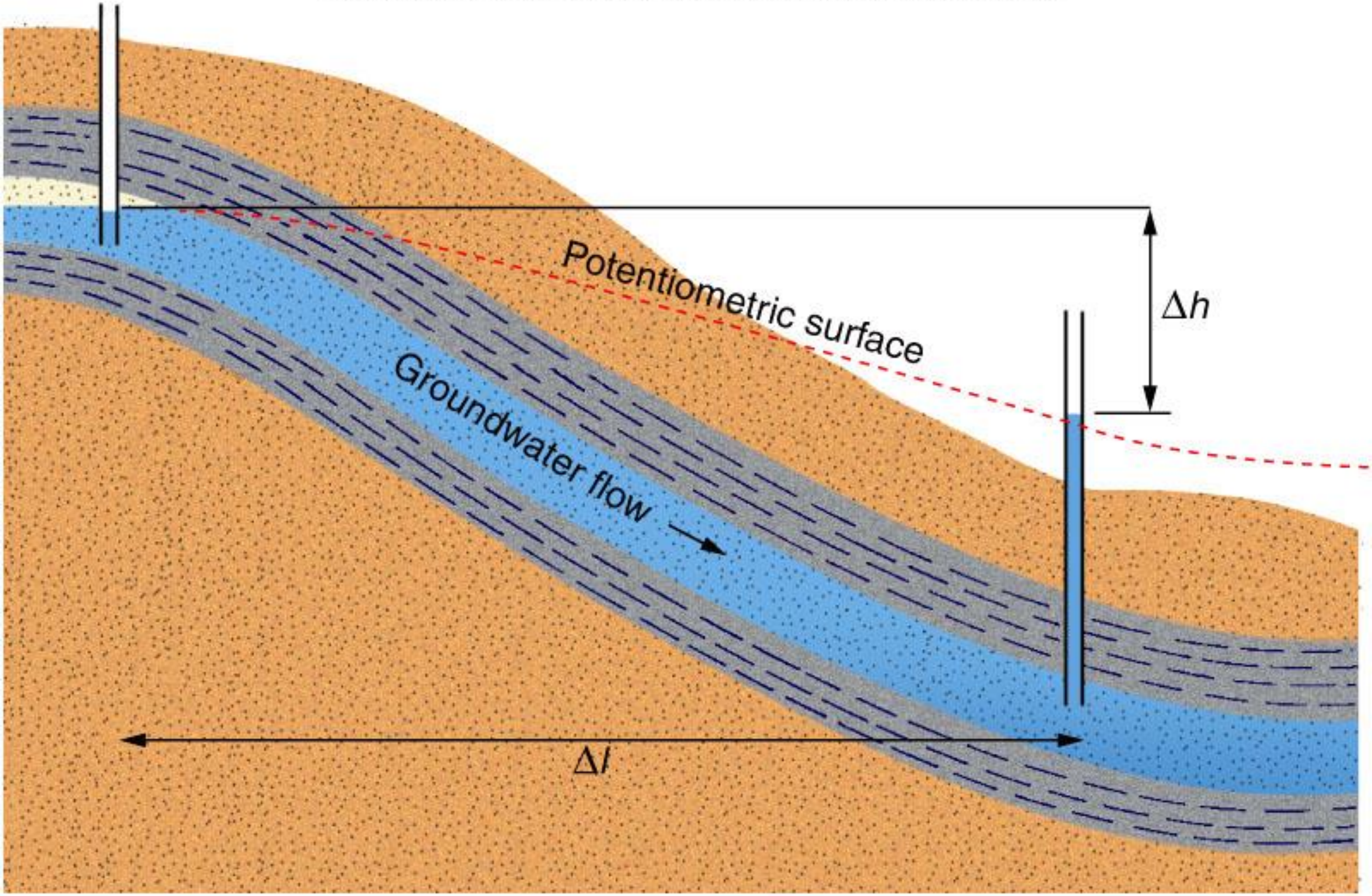

Springs

- Whenever the water table intersects Earth's surface, a natural outflow of groundwater results, which we call **a spring**.
- Another situation leading to the formation of a spring is illustrated in the Figure. Here an aquitard is situated above the main watertable. As water percolates downward, a portion of it is intercepted by the aquitard, thereby creating a localized zone of saturation and a **perched water table**.

Natural Springs

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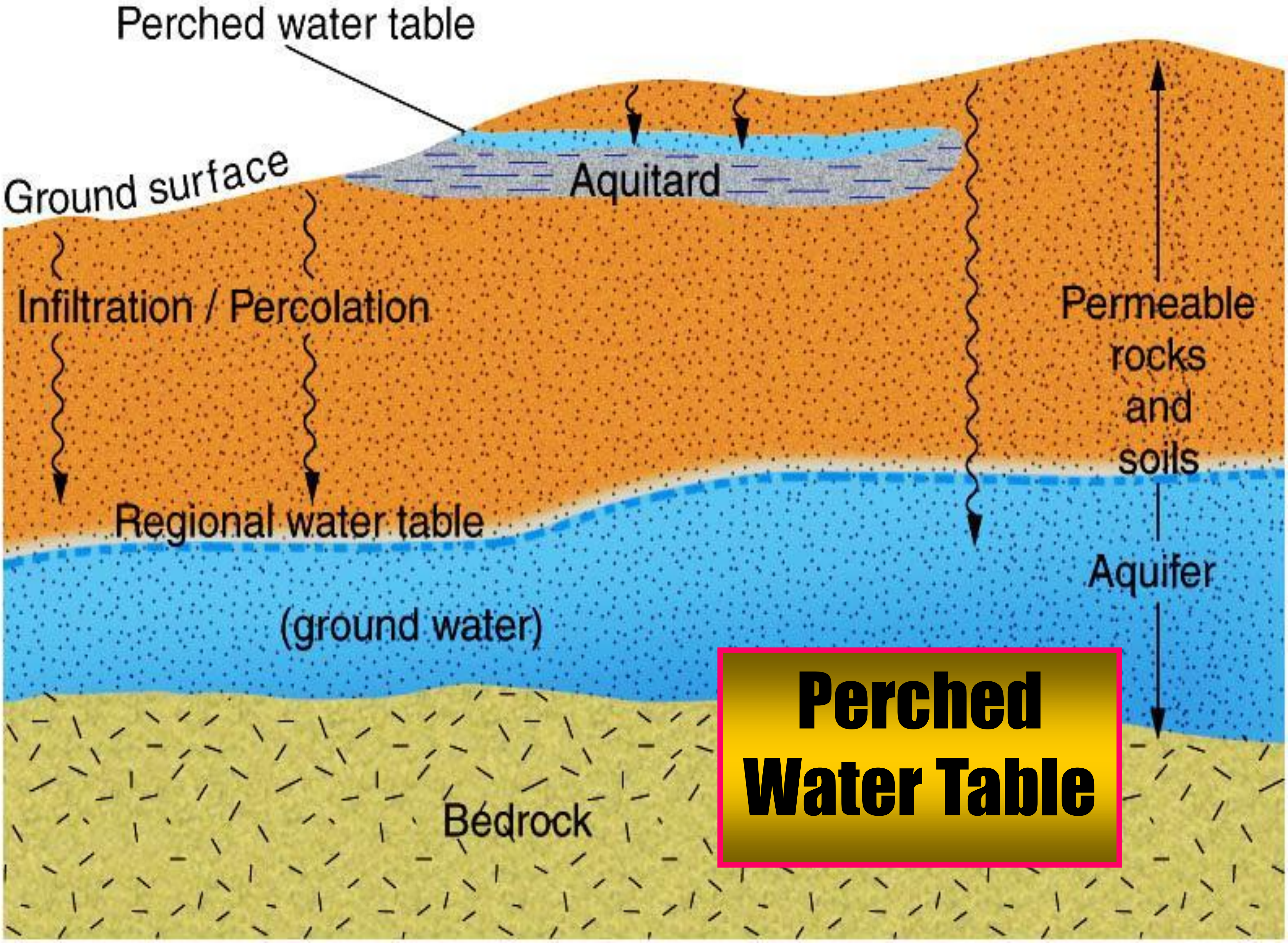
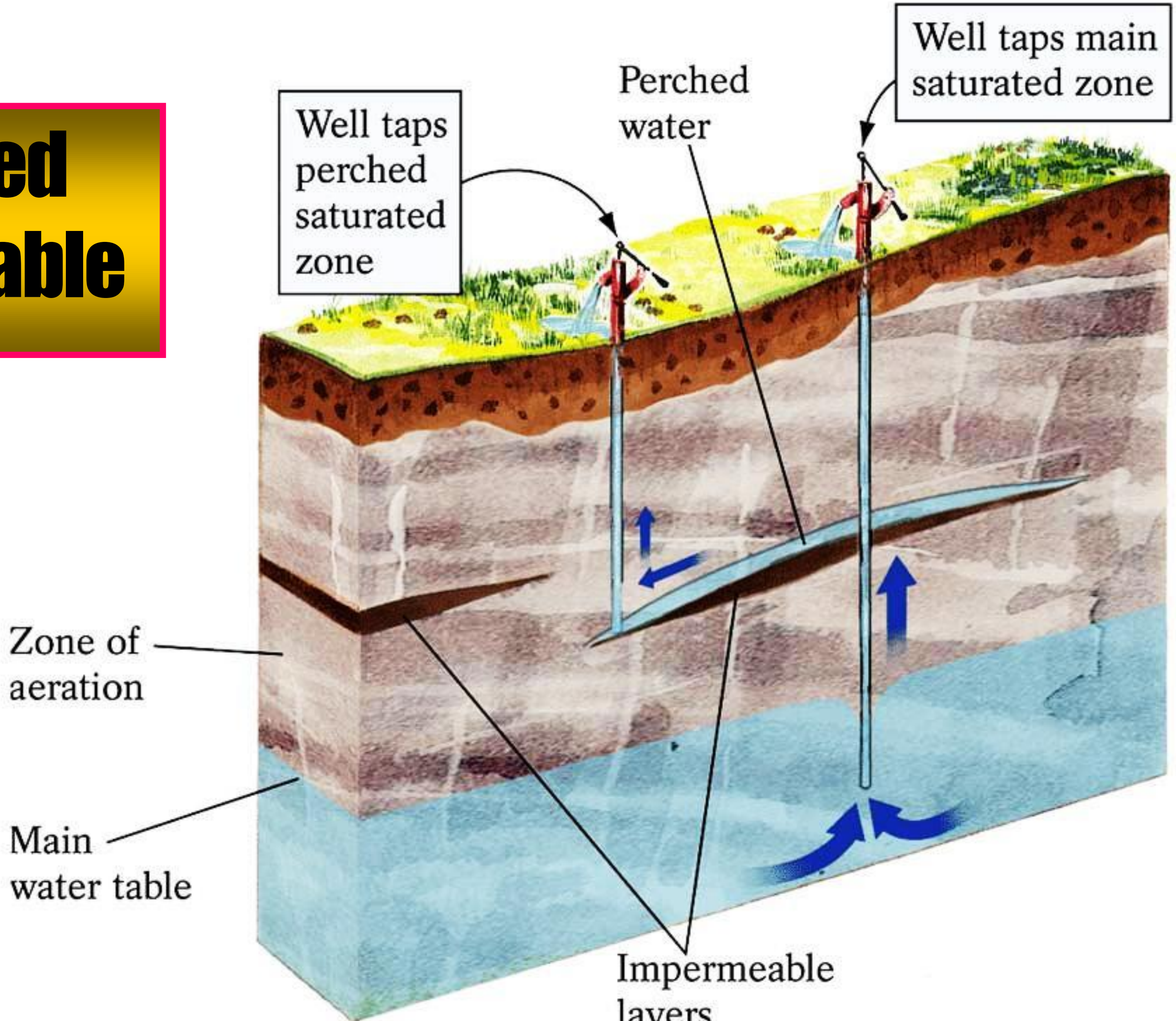


Perched Water Table

Perched Water Table



Geysers

Hot springs and Geysers

- By definition, the water in **hot springs** is 6-9°C warmer than the mean annual air temperature for the localities where they occur. Temperatures in deep mines and oil wells usually rise with increasing depth, an average of about 2°C per 100 meters. Therefore, when groundwater circulates at great depths, it becomes heated. If it rises to the surface, the water may emerge as a hot spring.
- **Geysers** are intermittent hot springs or fountains in which columns of water are ejected with great force at various intervals, often rising 30-60 meters (100-200 feet) into the air.

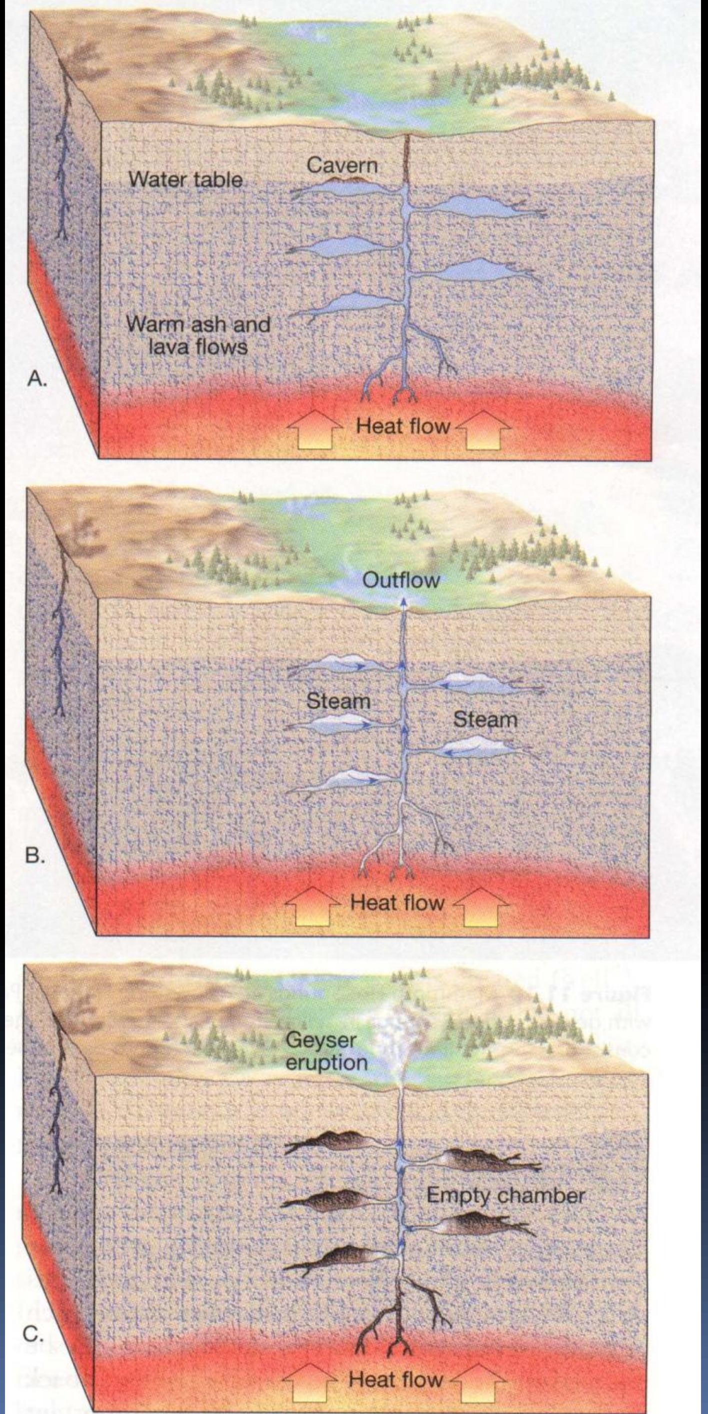
Hot springs and Geysers

- After the jet of water ceases a column of steam rushes out, usually with a thunderous roar. Perhaps the most famous geyser in the world is Old Faithful in Yellowstone National Park, which erupts about once each hour.
- Geysers occur where extensive underground chambers exist within hot igneous rocks. As relatively cool groundwater enters the chambers, it is heated by the surrounding rock. At the bottom of the chambers, the water is under great pressure because of the weight of the overlying water. This great pressure prevents the water from boiling at the normal surface temperature of 100°C.
- The heating causes the water to expand, with the result that some is forced out at the surface.

Hot springs and Geysers

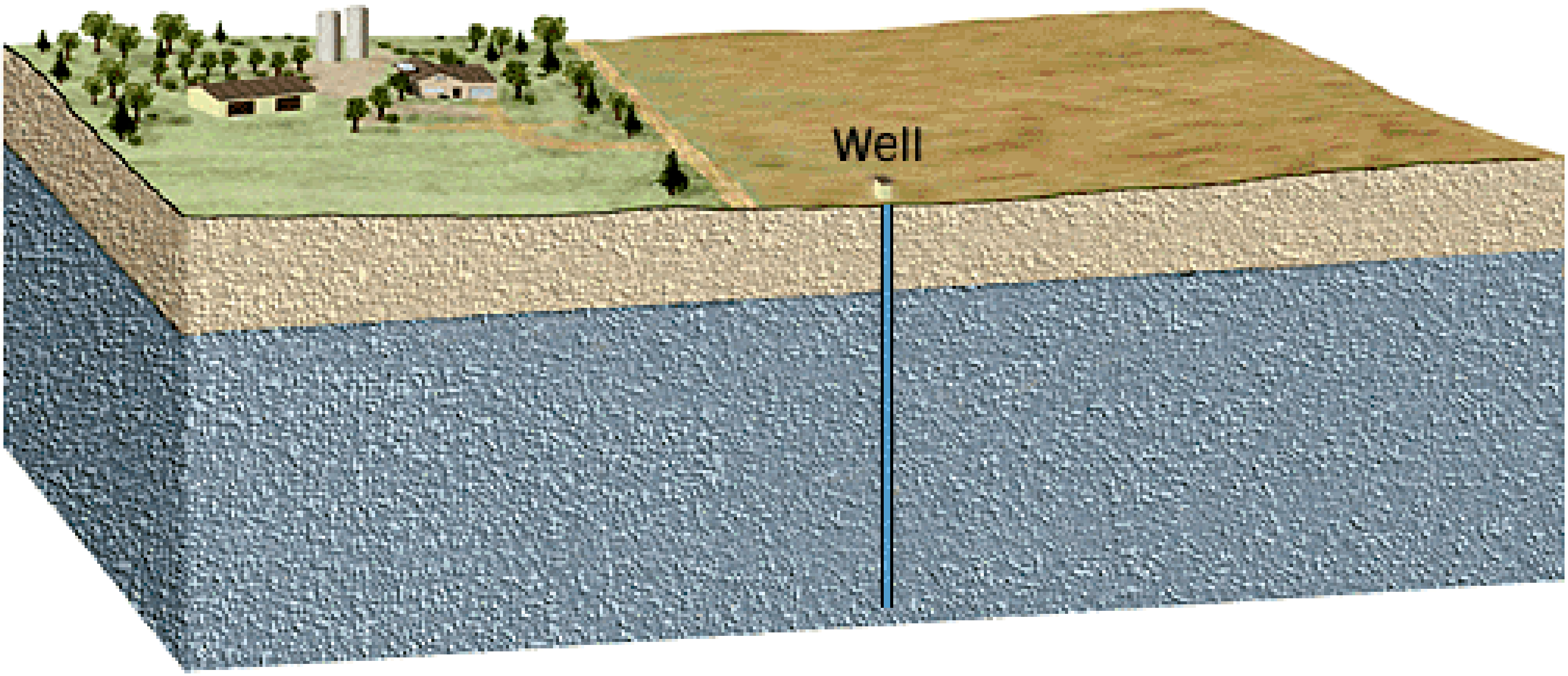
- This loss of water reduces the pressure on the remaining water in the chamber, which lowers the boiling point. A portion of the water deep within the chamber quickly turns to steam and the geyser erupts.
- The material deposited at any given place commonly reflects the chemical makeup of the rock through which the water circulated. When the water contains dissolved silica, a material called **siliceous sinter** or geyserite is deposited around the spring. When the water contains dissolved calcium carbonates, a form of limestone called **travertine or calcareous tufa** is deposited.

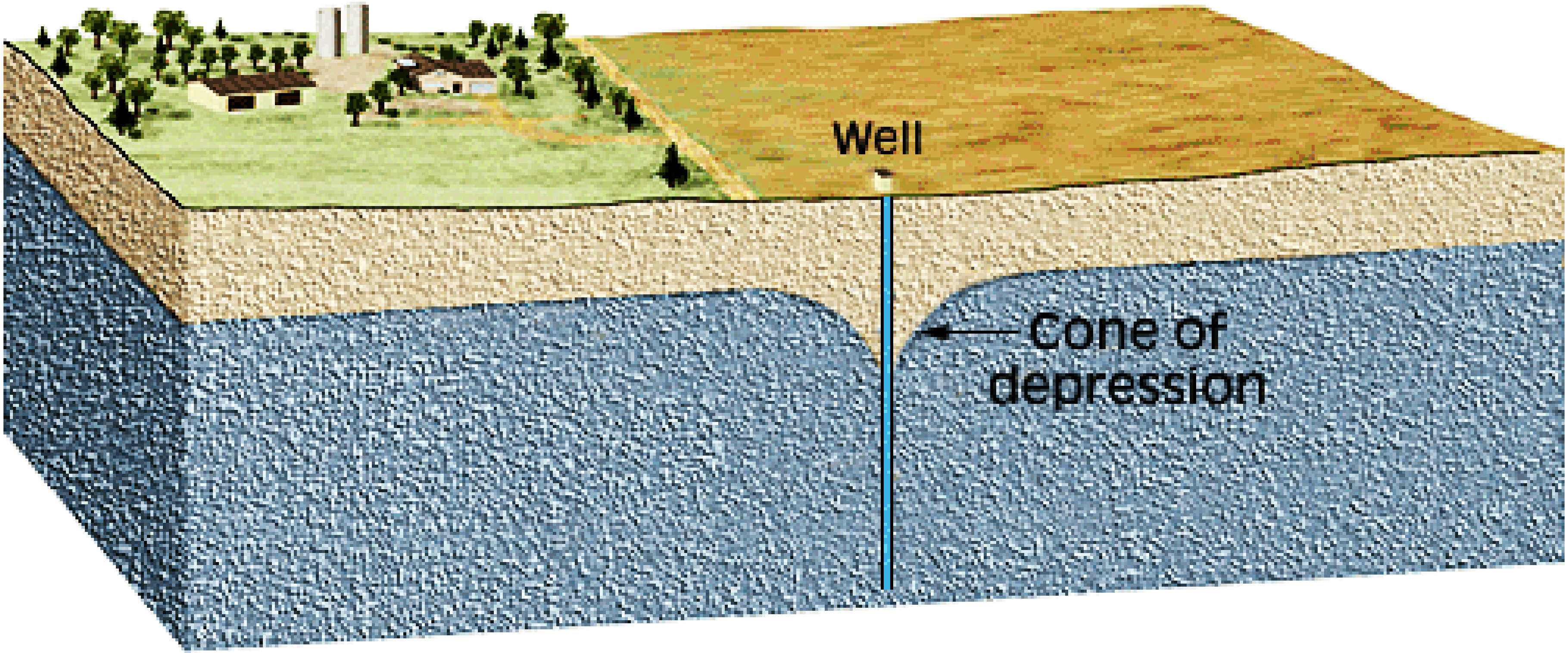
Idealized diagrams of a geyser. A geyser can form if the heat is not distributed by convection. A. In this figure, the water near the bottom is heated to near its boiling point. The boiling point is higher there than at the surface because the weight of the water above increases the pressure. B. The water higher in the geyser system is also heated; therefore, it expands and flows out at the top, reducing the pressure on the water at the bottom. C. At the reduced pressure on the bottom, boiling occurs. Some of the bottom water flashes into steam, and the expanding steam causes an eruption.

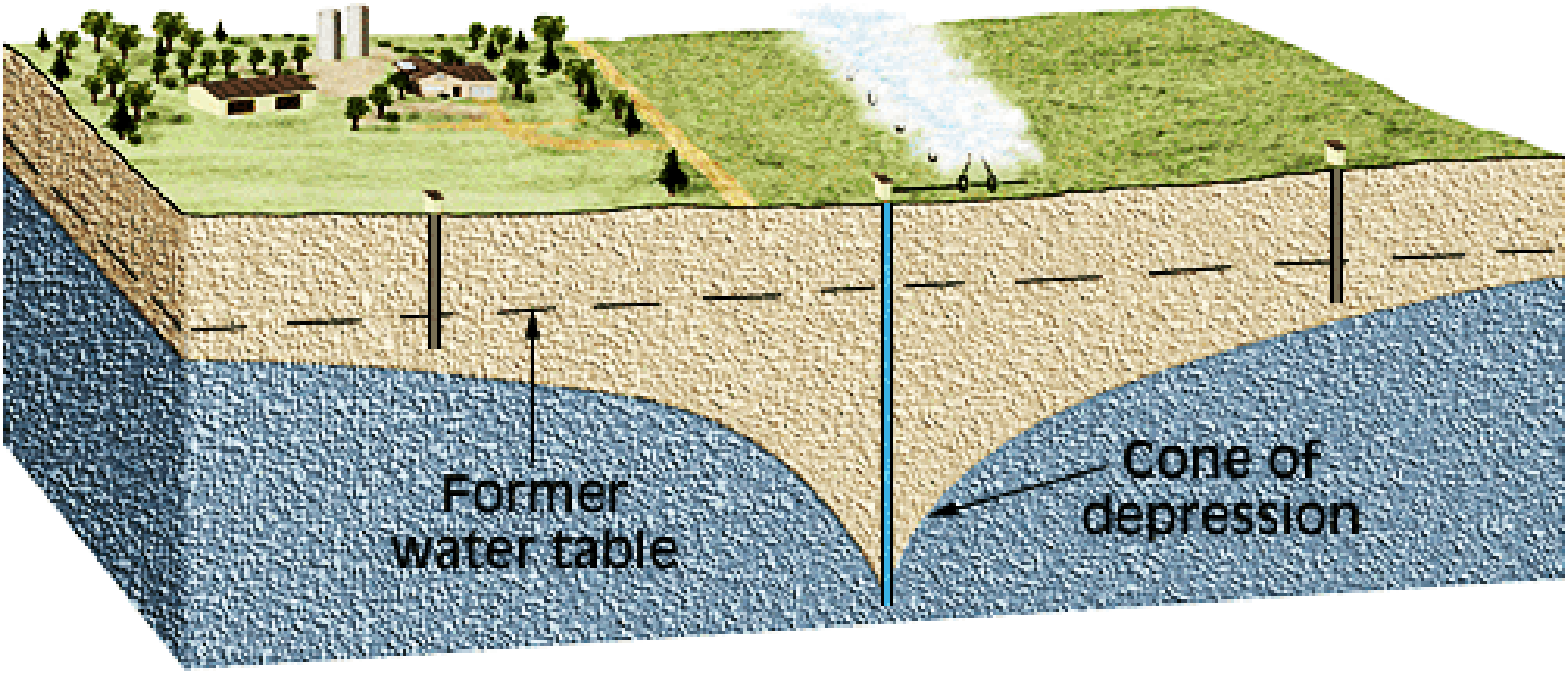


Wells

- The most common method for removing groundwater is the **well**, a hole bored into the zone of saturation. Wells serve as small reservoirs into which groundwater migrates and from which it can be pumped to the surface.
- The water table level may fluctuate considerably during the course of a year, dropping during the dry seasons and rising following periods of rain. Therefore, to ensure a continuous supply of water, a well must penetrate below the water table. Whenever water is withdrawn from a well, the water table around the well is lowered. This effect, termed **drawdown**, decreases with increasing distance from the well. The result is a depression in the water table, roughly conical in shape, known as **a cone of depression.**

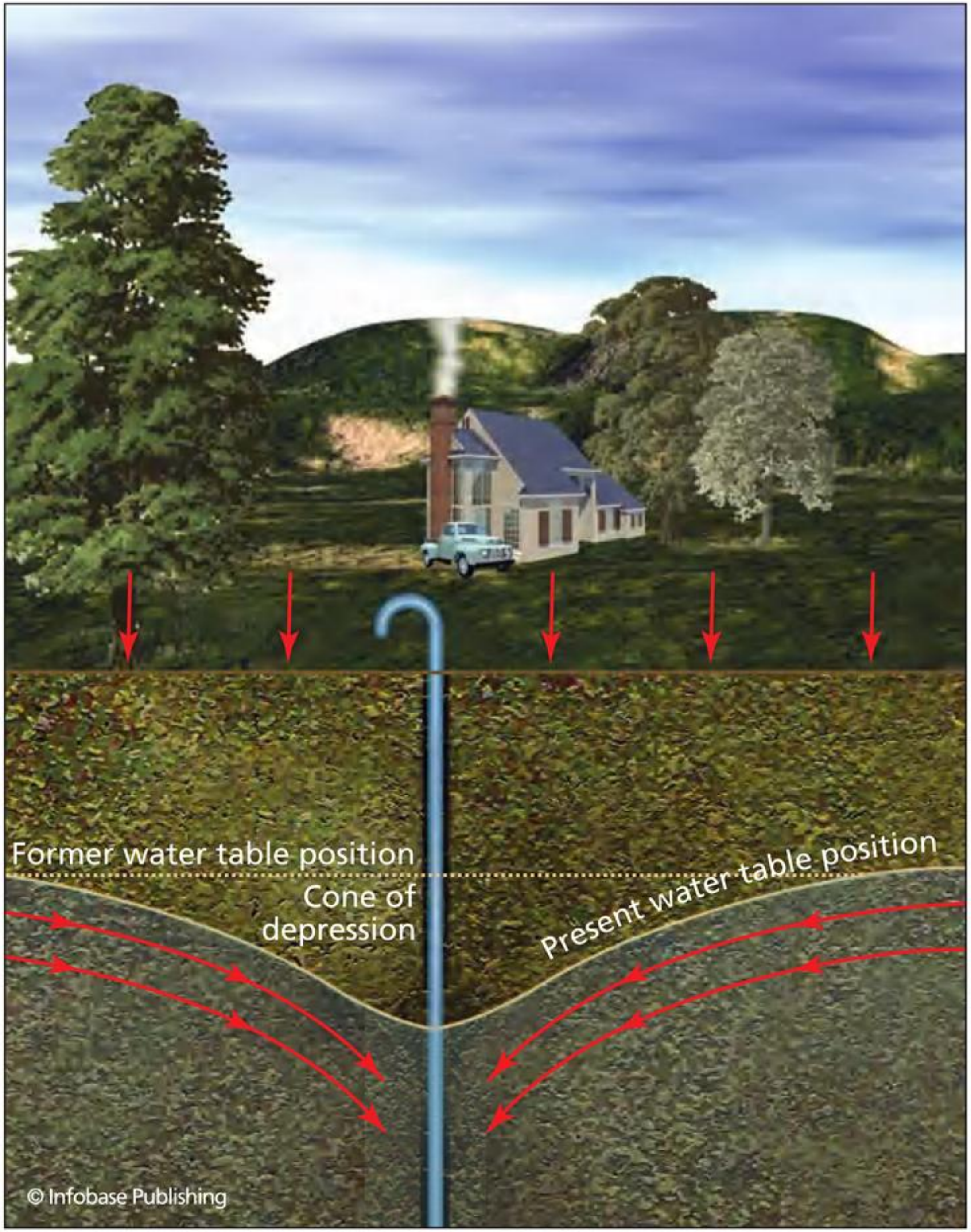

Well


Well
Cone of
depression

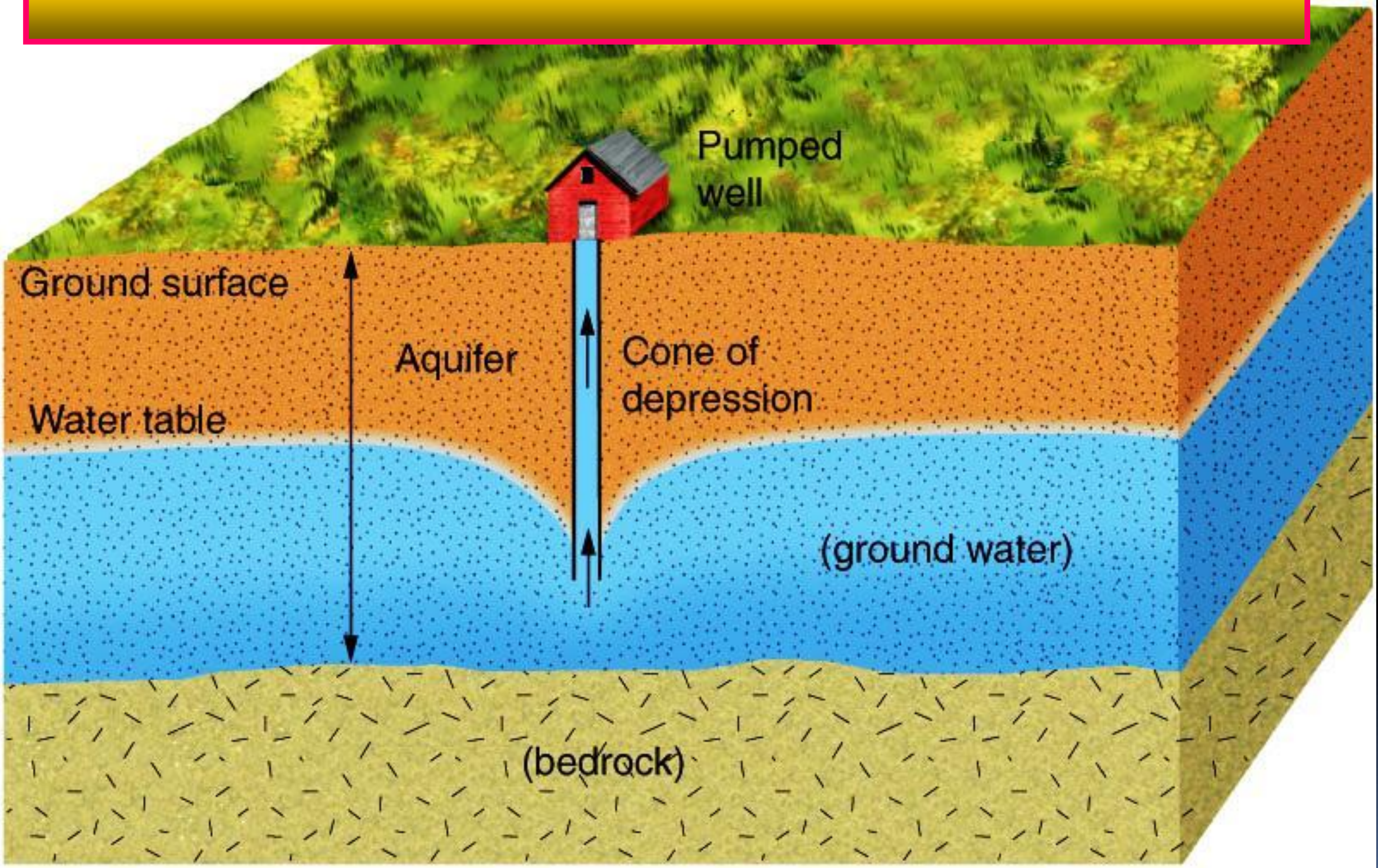


If heavy pumping lowers the water table, the shallow wells may be left dry.

When users pump a well faster than nearby sources can replenish it, the water level drops around the well, forming a cone in which the water table is depressed.

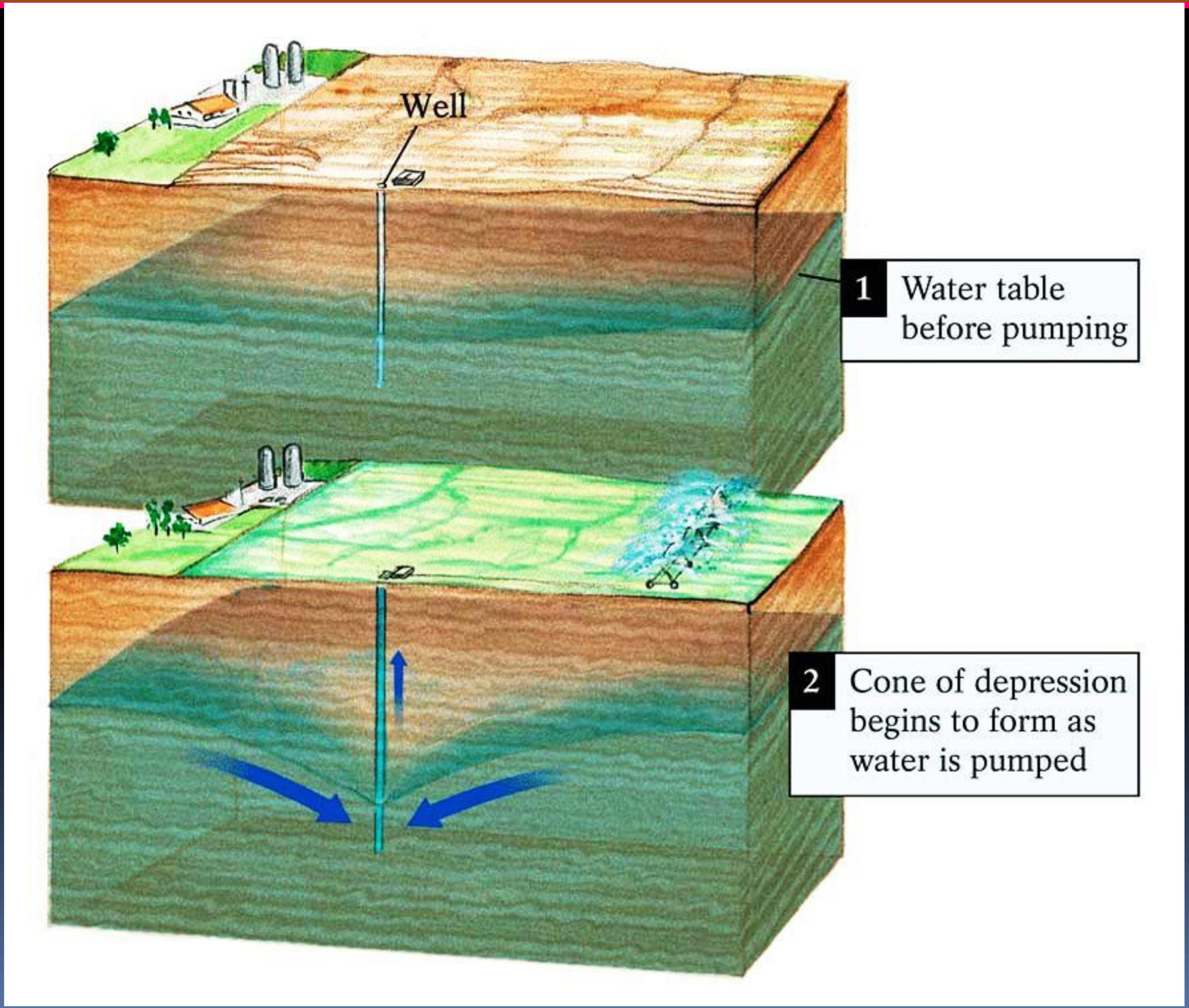


Drawdown of the Water Table

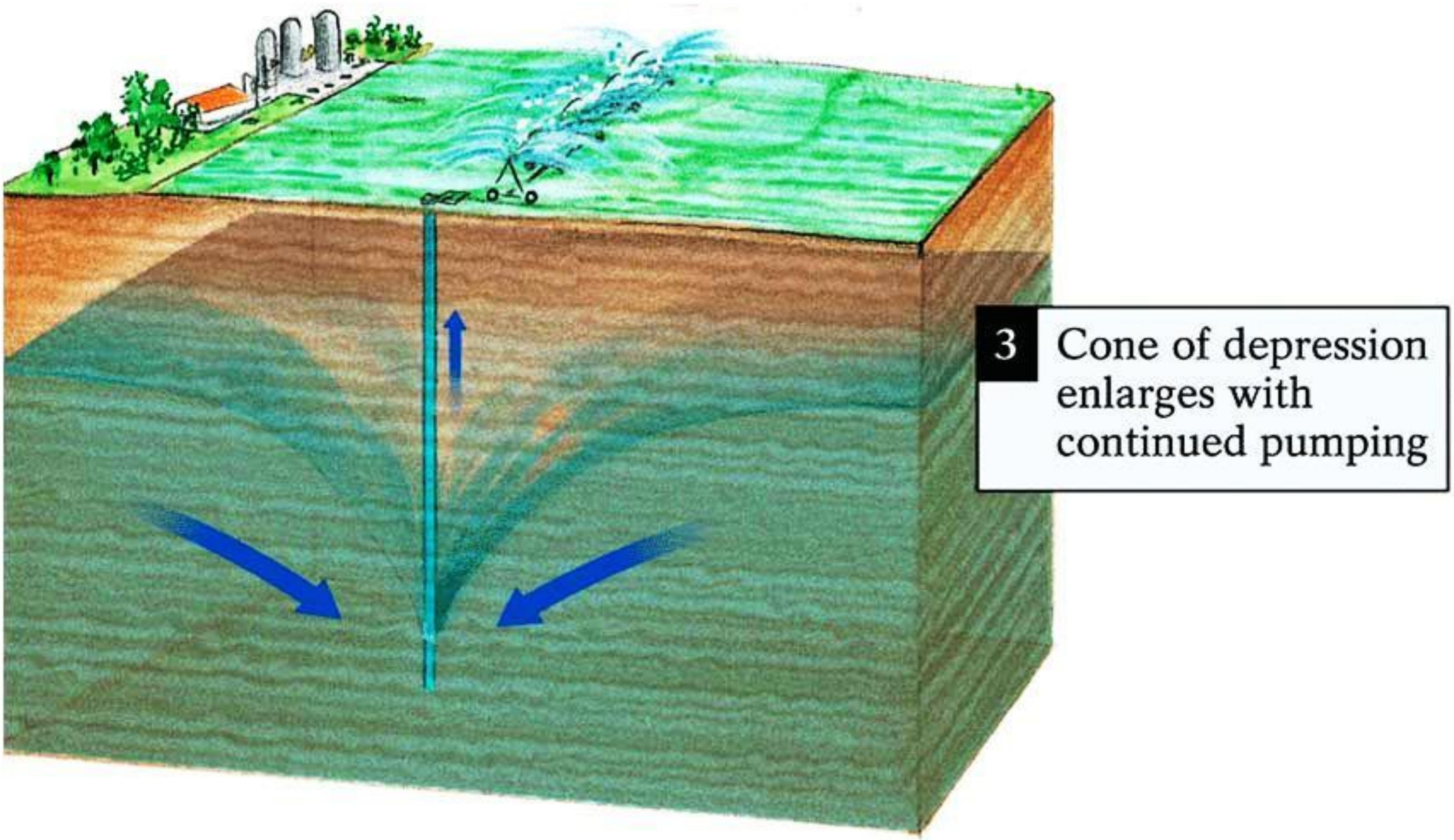


A

Drawdown of the Water Table



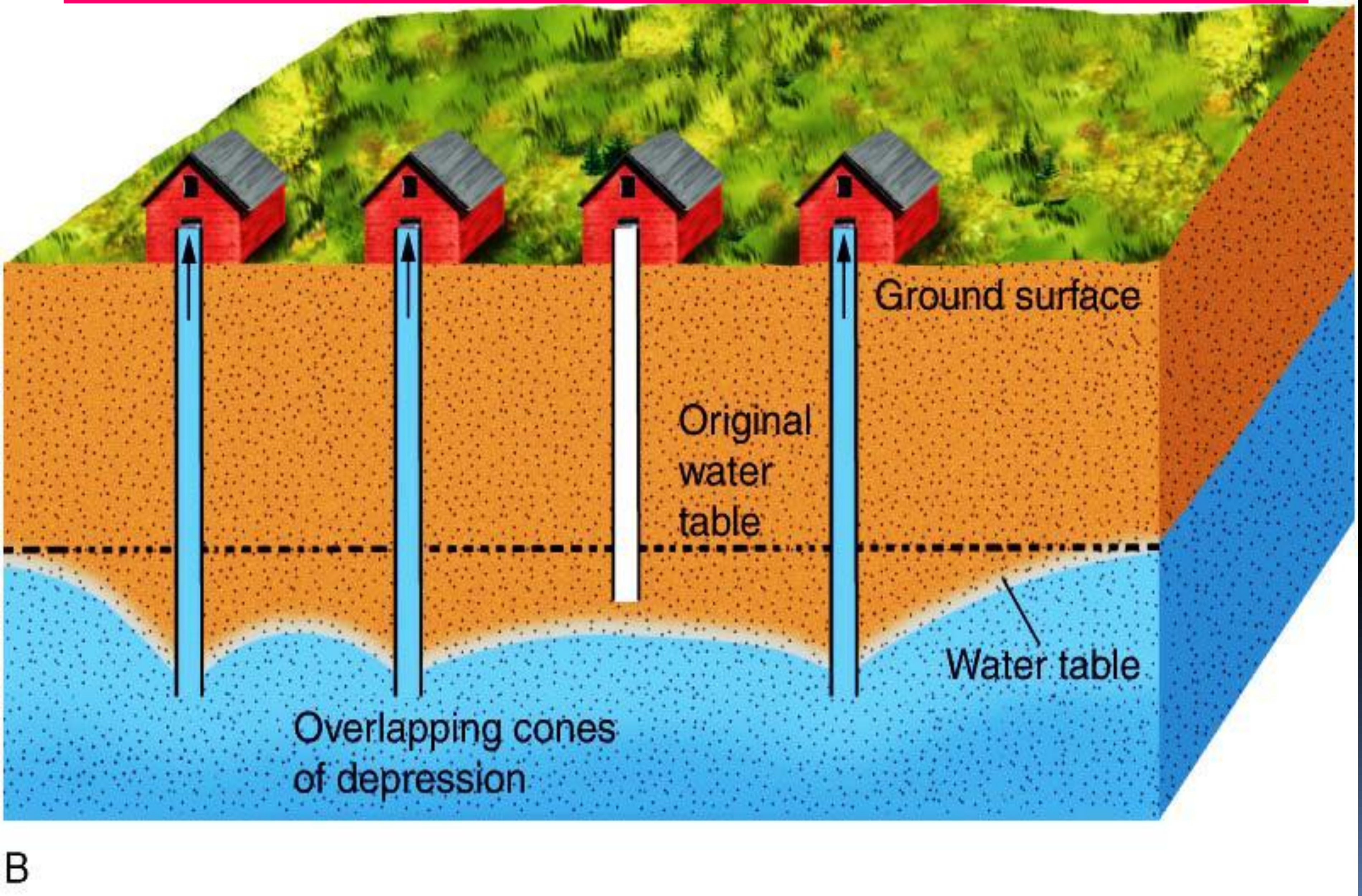
Drawdown of the Water



Wells

- Because the cone of depression increases the hydraulic gradient near the well, groundwater will flow more rapidly toward the opening.
- When wells are heavily pumped for irrigation or for industrial purposes, the withdrawal of water can be great enough to create a very wide and steep cone of depression. This may substantially lower the water table in an area and cause nearby shallow wells to become dry.
- **Artesian Wells**
- in some wells, water rises, sometimes overflowing at the surface. Such wells are abundant in the ***artois*** region of northern France, and so we call these self-rising wells ***artesian***.
-

Overlapping cones of Depression



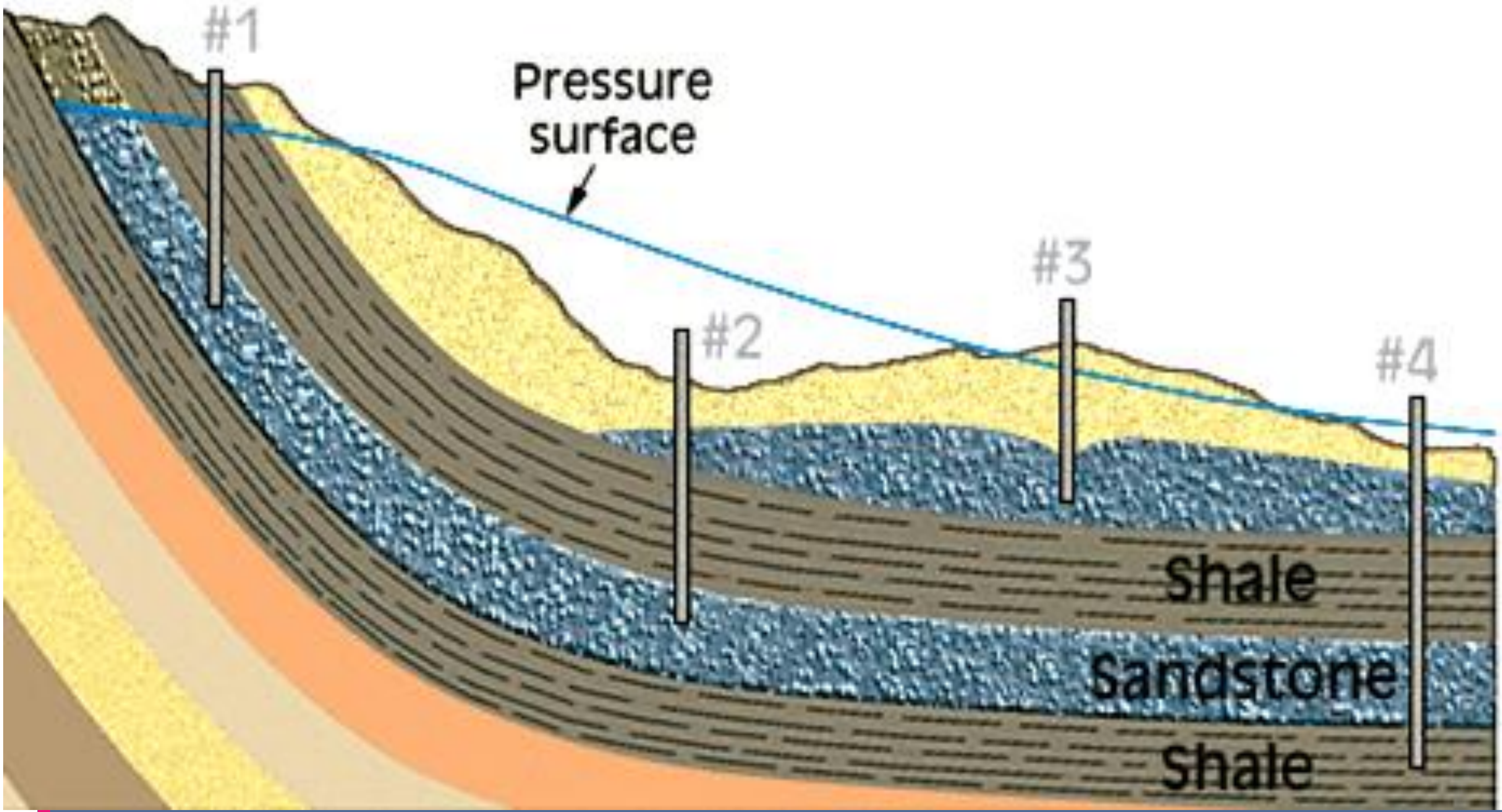
Artesian Wells

- The term ***artesian*** is applied to ***any*** situation in which groundwater under pressure rises above the level of the aquifer. This does not always mean a free-flowing surface discharge.
- For an artesian system to exist, two conditions must be met: (1) water must be confined to an aquifer that is inclined so that one end can receive water; and (2) aquitards, both above and below the aquifer, must be present to prevent the water from escaping. When such a layer is tapped, the pressure created by the weight of the water above will force the water to rise.

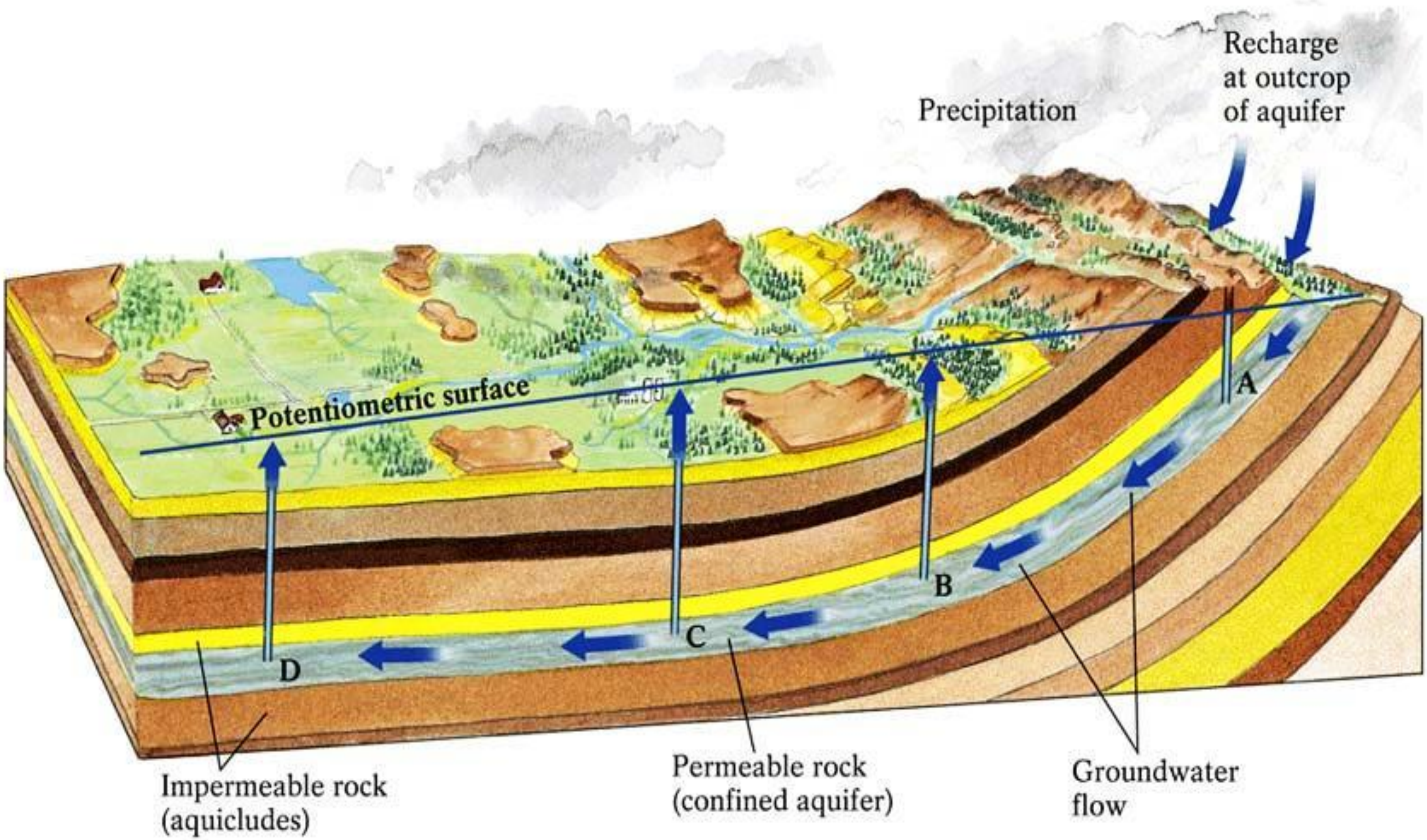
Artesian Wells

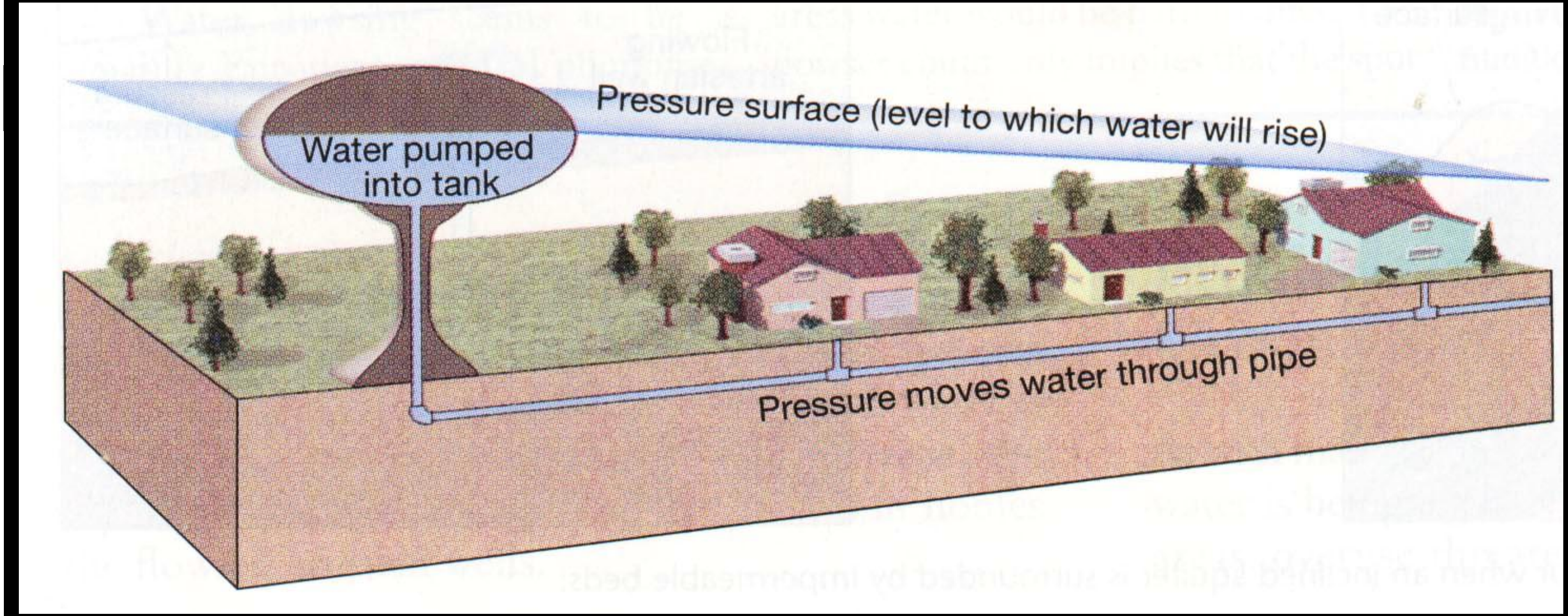
- In the Figure, well 1 is a ***nonflowing artesian well***, because at this location the pressure surface is below ground level. When the pressure surface is above the ground and a well is drilled into the aquifer, ***a flowing artesian well*** is created (well 2, Figure 11.13). It is important to realize that not all artesian systems are wells. *Artesian springs* also exist. Here groundwater reaches the surface by rising through a natural fracture rather than through an artificially produced hole.
- On a different scale, city water systems can be considered examples of ***artificial artesian systems*** (Figure 11.15). The water tower, into which water is pumped, would represent the area of recharge, the pipes the confined aquifer, and the faucets in homes the flowing artesian wells.

Artesian Wells



Artesian Aquifers





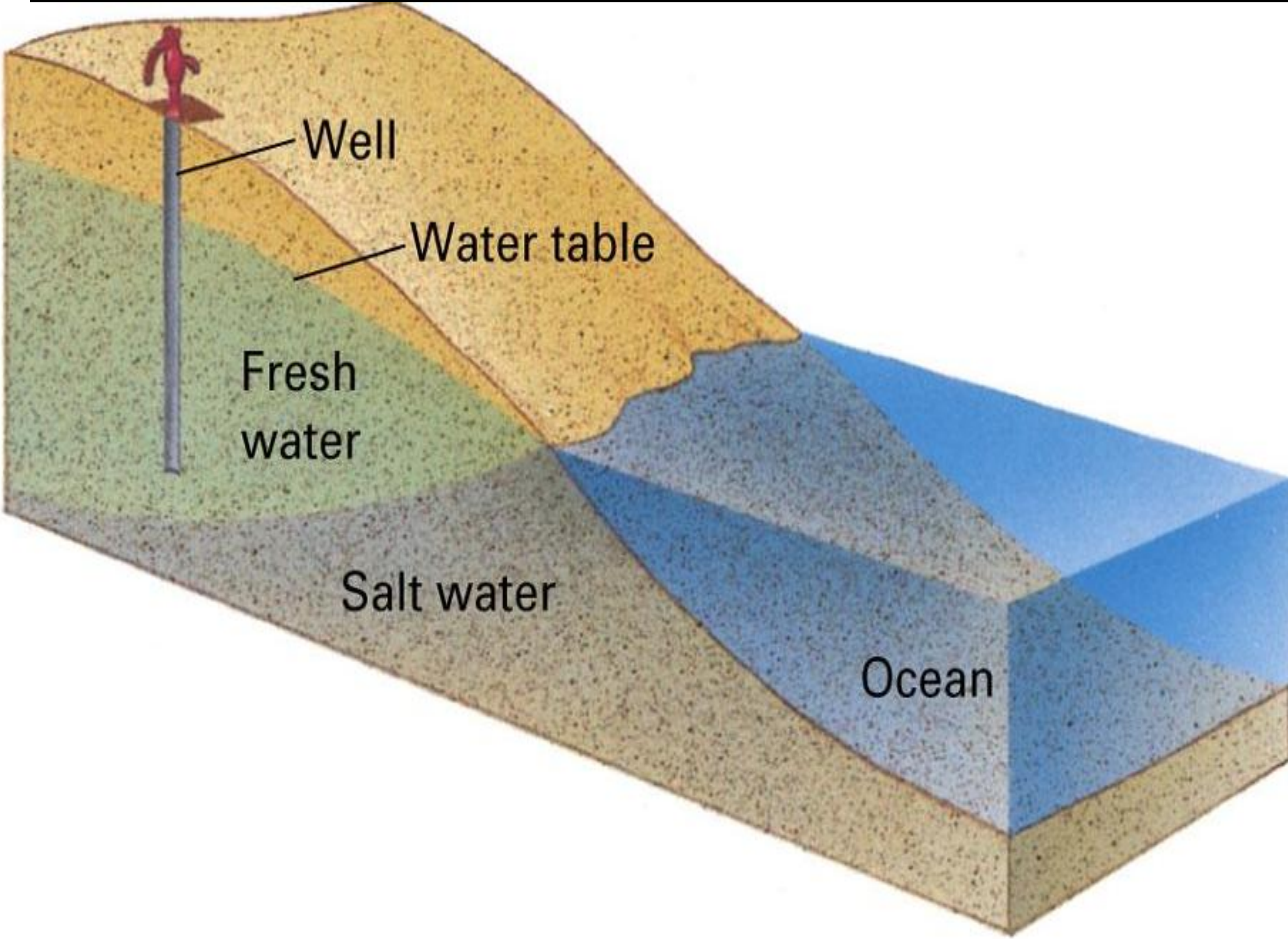
City water systems can be considered to be artificial artesian systems

Treating Groundwater as a Nonrenewable Resource

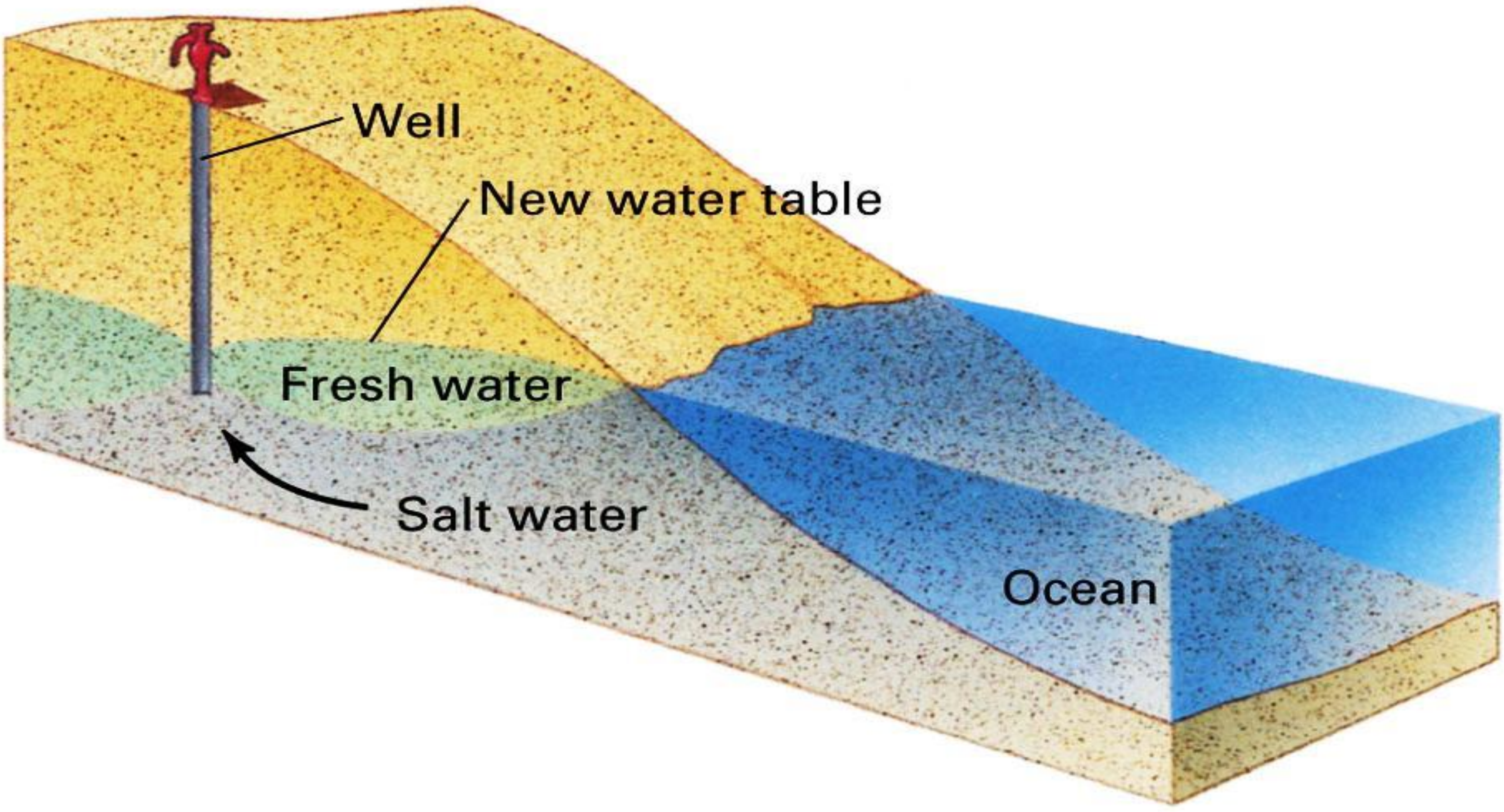
- The water table's height reflects a balance between the rate of infiltration and the rate of discharge and withdrawal. Any imbalance will either raise or lower the water table.
- For many, groundwater appears to be and endlessly renewable resource, because it is continually replenished by rainfall and melting snow. But in some regions, groundwater has been and continues to be treated as a ***nonrenewable*** resource.
- **Subsidence**
- surface subsidence can result from natural processes related to groundwater. However, the ground may also sink when water is pumped from wells faster than natural recharge processes can replace it. This effect is particularly pronounced in areas underlain by thick layers of unconsolidated sediments.

Saltwater Contamination

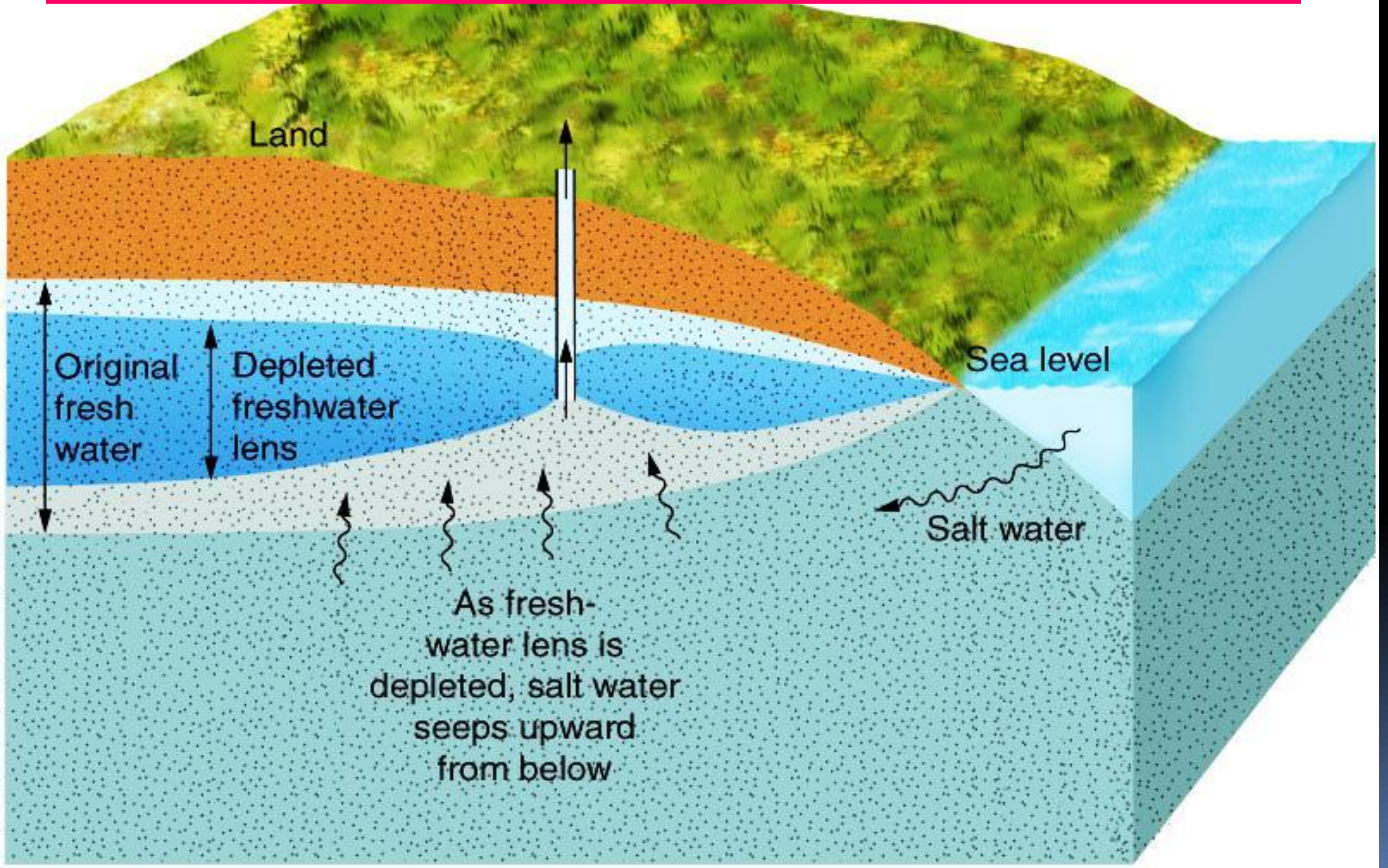
- In many coastal areas the groundwater resource is being threatened by the encroachment of salt water.
- Figure 11.17A is a diagrammatic cross-section that illustrates this relationship in a coastal area underlain by permeable homogenous materials. Fresh water is less dense than salt water, so it floats on the salt water and forms a large, lens-shaped body that may extend to considerable depths below sea level. In such a situation, if the water table is 1 meter above sea level, the base of the freshwater body will extend to a depth of about 40 meters below sea level.
- Thus, when excessive pumping lowers the water table by a certain amount, the bottom of the freshwater zone will rise by 40 times that amount.


Well
Water table
Fresh water
Salt water
Ocean

Salt Water Intrusion



Salt Water Intrusion



Saltwater Contamination

- withdrawal continues to exceed recharge, there will come a time when the elevation of the salt water will be sufficiently high to be drawn into wells, thus contaminating the freshwater supply (Figure 11.17B).
- **Groundwater Contamination**
- One common source of groundwater pollution is sewage. Its sources include an ever increasing number of septic tanks, as well as inadequate or broken sewer systems and farm wastes.
- If sewage water that is contaminated with bacteria enters the groundwater system, it may become purified through natural processes.

Groundwater Contamination

- For purification to occur, however, the aquifer must be of the correct composition. For example, extremely permeable aquifers have such large openings that contaminated groundwater may travel long distances without being cleansed. In this case, the water flows too rapidly and is not in contact with the surrounding material long enough for purification to occur. This is the problem at well 1 in Figure 11.18A.
- On the other hand, when the aquifer is composed of sand or permeable sandstone, it can sometimes be purified after traveling only a few dozen meters through it. The openings between sand grains are large enough to permit water movement, yet the movement of the water is slow enough to allow ample time for its purification (well 2, Figure 11.18B).

Groundwater Contamination

- Sometimes sinking a well can lead to groundwater pollution problems. If the well pumps a sufficient quantity of water, the cone of depression will locally increase the slope of the water table. In some instances, the original slope may even be reversed. This could lead to the contamination of wells that yielded unpolluted water before heavy pumping began (Figure 11.19).
- Other sources and types of contamination also threaten groundwater supplies (Figure 11.20). These include widely used substances such as highway salt, fertilizers that are spread across the land surface, and pesticides. In addition, a wide array of chemicals and industrial materials may leak from pipelines, storage tanks, and landfills. Some of these pollutants are classified as ***hazardous***, meaning that they are either flammable, corrosive, explosive, or toxic.

The Geologic Work of Groundwater

- Limestone is nearly insoluble in pure water, but is quite easily dissolved by water containing small quantities of carbonic acid, and most groundwater contains this acid.
- Therefore, when groundwater comes in contact with limestone, the carbonic acid reacts with the calcite (calcium carbonate) in the rocks to form calcium bicarbonate, a soluble material that is then carried away in solution.
- **Caverns**
- The most spectacular results of groundwater's erosional handiwork are limestone ***caverns***.

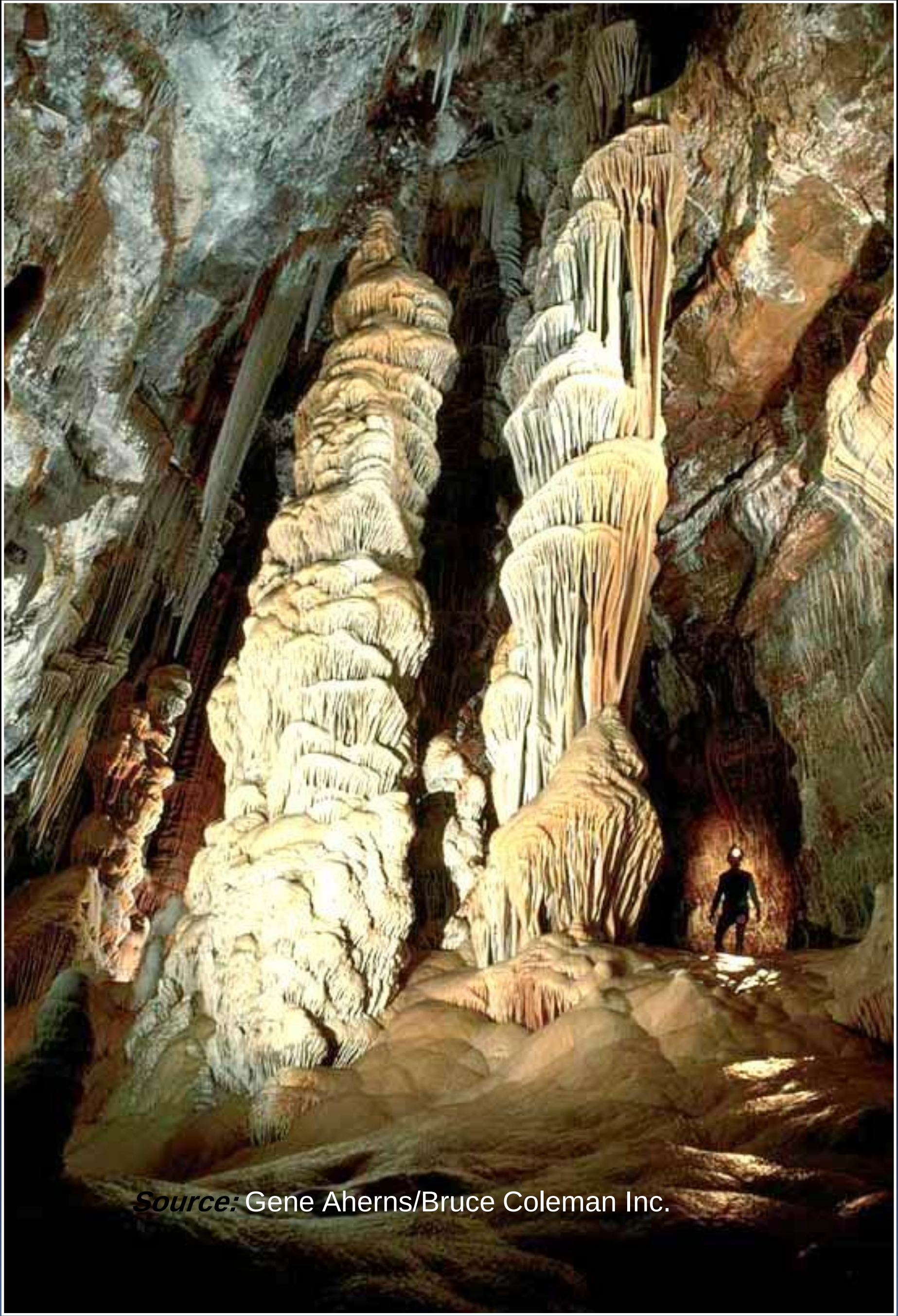
Caverns

- Most caverns are created at or just below the water table in the zone of saturation.
- Certainly the features that arouse the greatest curiosity for most cavern visitors are the stone formations that give some caverns a wonderland appearance. These are not erosional features, like the cavern itself, but depositional features created by the seemingly endless dripping of water over great spans of time.
- The various dripstone features found in caverns are collectively called ***speleothems***, no two of which are exactly alike. Perhaps the most familiar speleothems are **stalactites.** These icicle-like pendants hang from the ceiling of the cavern and form where water seeps through cracks above.

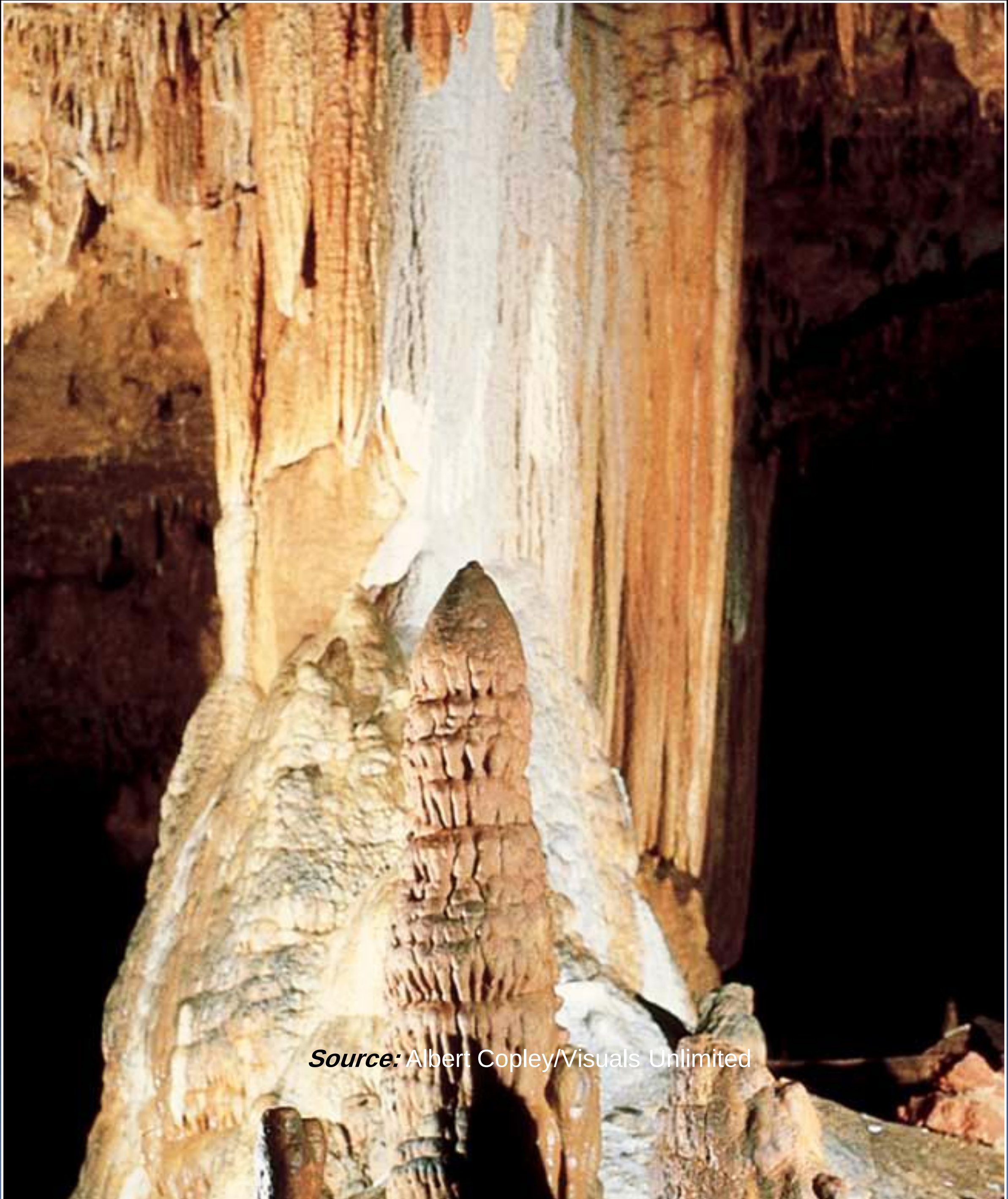
Caverns

- When the water reaches air in the cave, some of the dissolved carbon dioxide escapes from the drop and calcite precipitates. Deposition occurs as a ring around the edge of the water drop. As drop after drop follows, a hollow limestone tube is created. Water then moves through the tube, remains suspended momentarily at the end, contributes a tiny ring of calcite, and falls to the cavern floor. This stalactite is called a ***soda straw .***
- Speleothems that form on the floor of a cavern and reach upward toward the ceiling are called ***stalagmites.***The water supplying the calcite for stalagmite growth falls from the ceiling and splatters over the surface. As a result, stalagmites do not have a central tube and are usually more massive in appearance and rounded on their upper ends than stalactites.

Cave Formations in Carlsbad Caverns National Park, New Mexico



Various Types of Speleothems (Stalactites and Stalagmites Merge)



Various Types of Speleothems

Source: Jeff Lepore/Photo Researchers Inc.

Stalactites and Stalagmites

Various Types of Speleothems

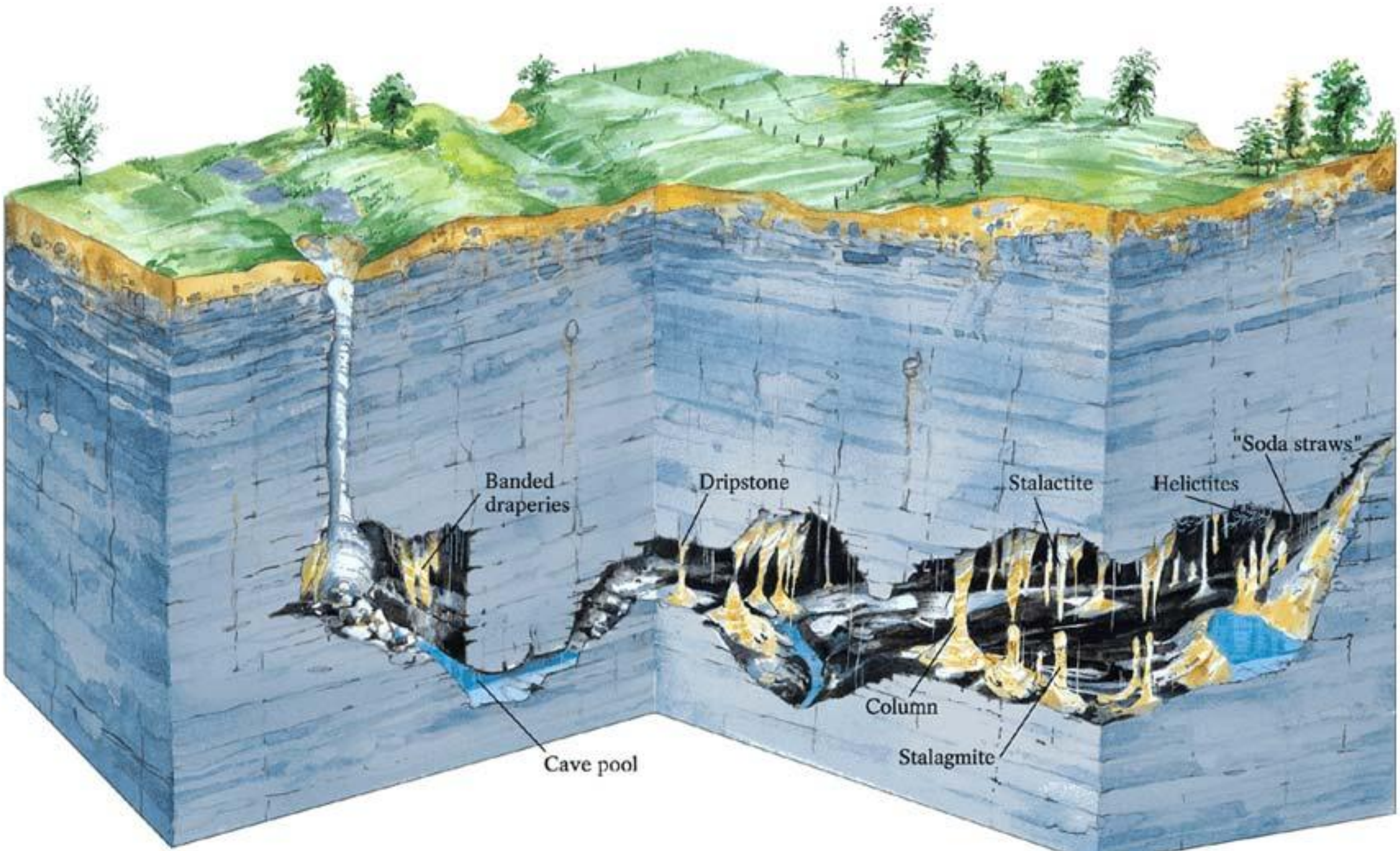
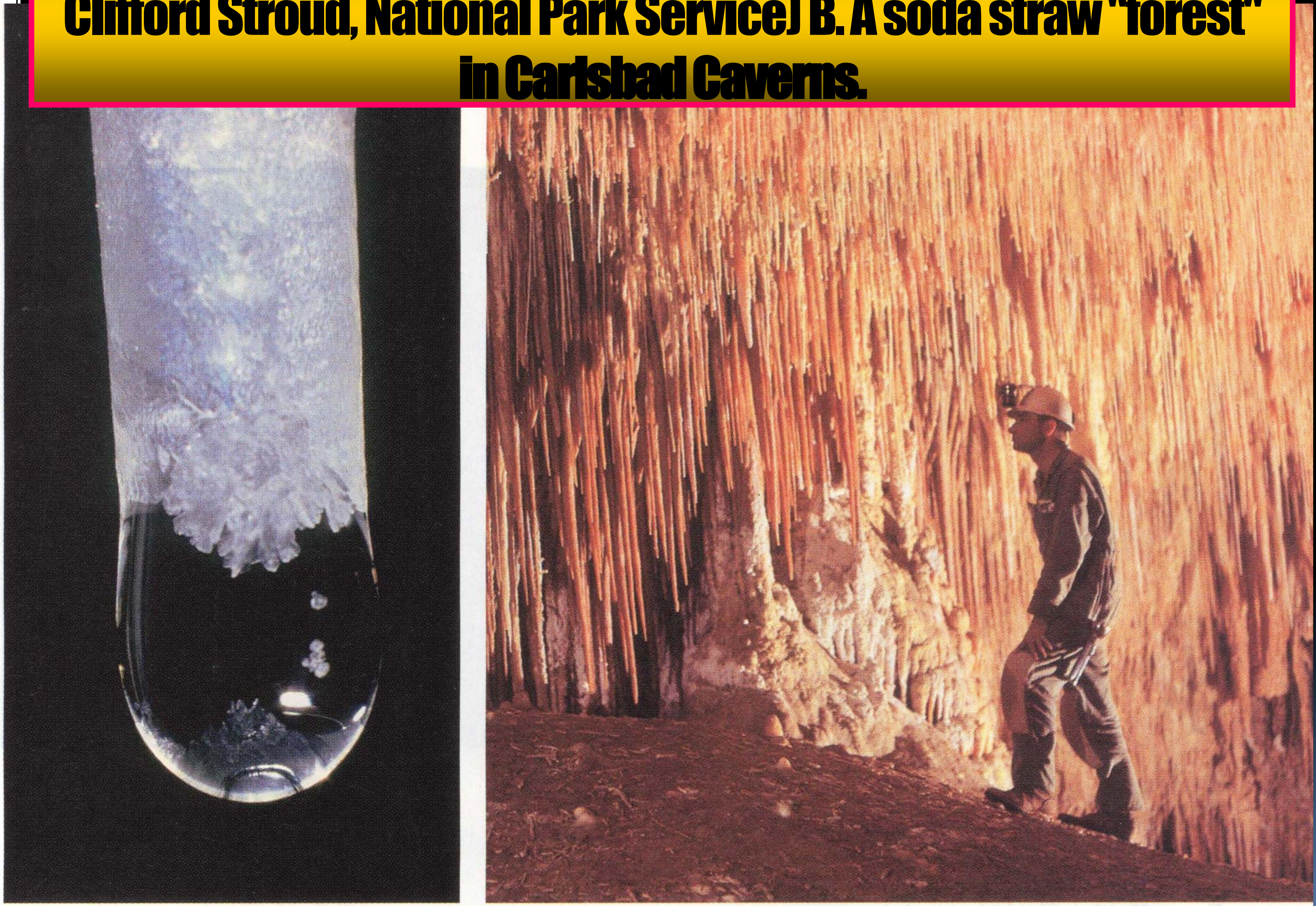


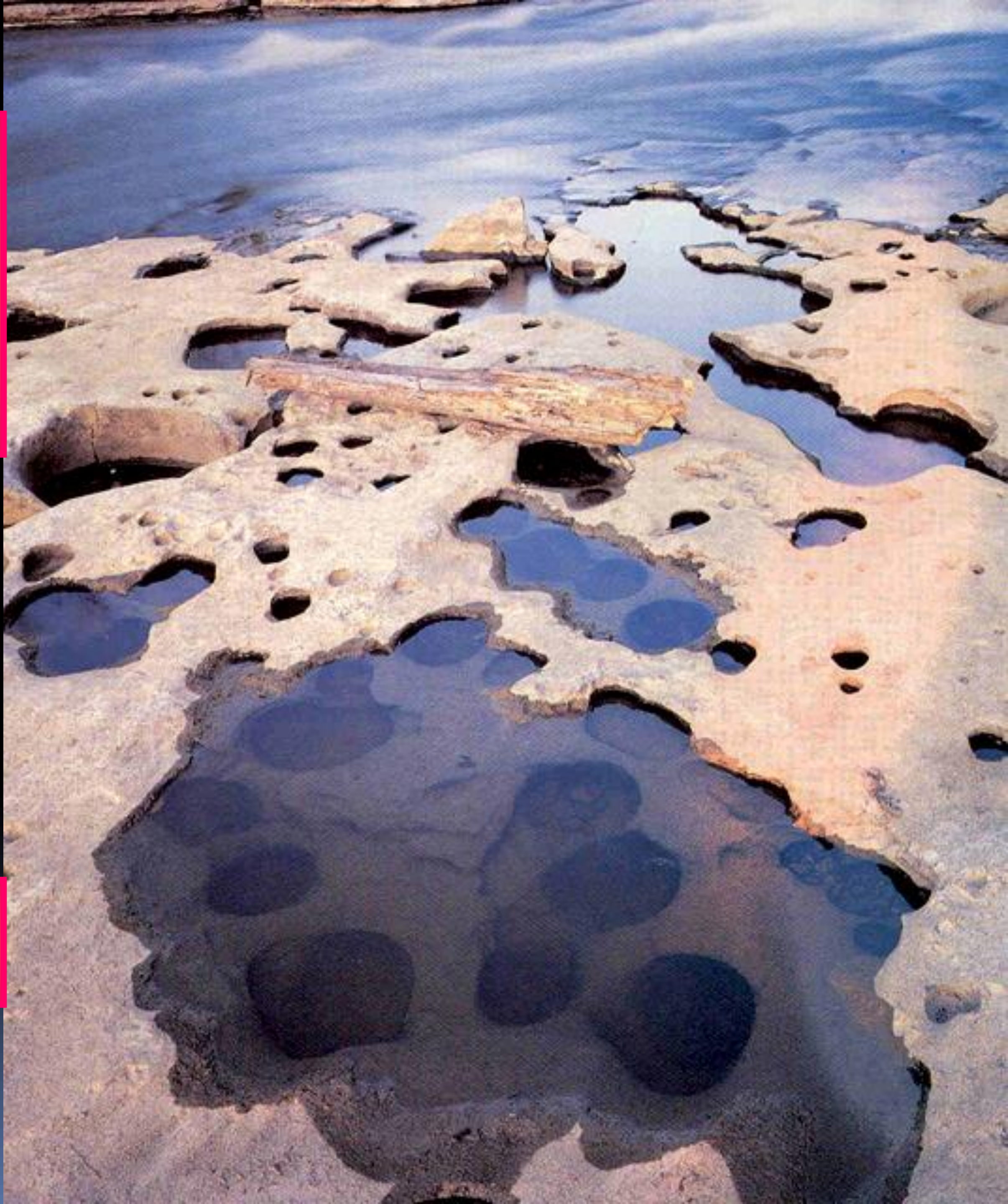
Figure 11.22 A. A "live" solitary soda straw stalactite. (Photo by Clifford Stroud, National Park Service) B. A soda straw "forest" in Carlsbad Caverns.



Karst Topography

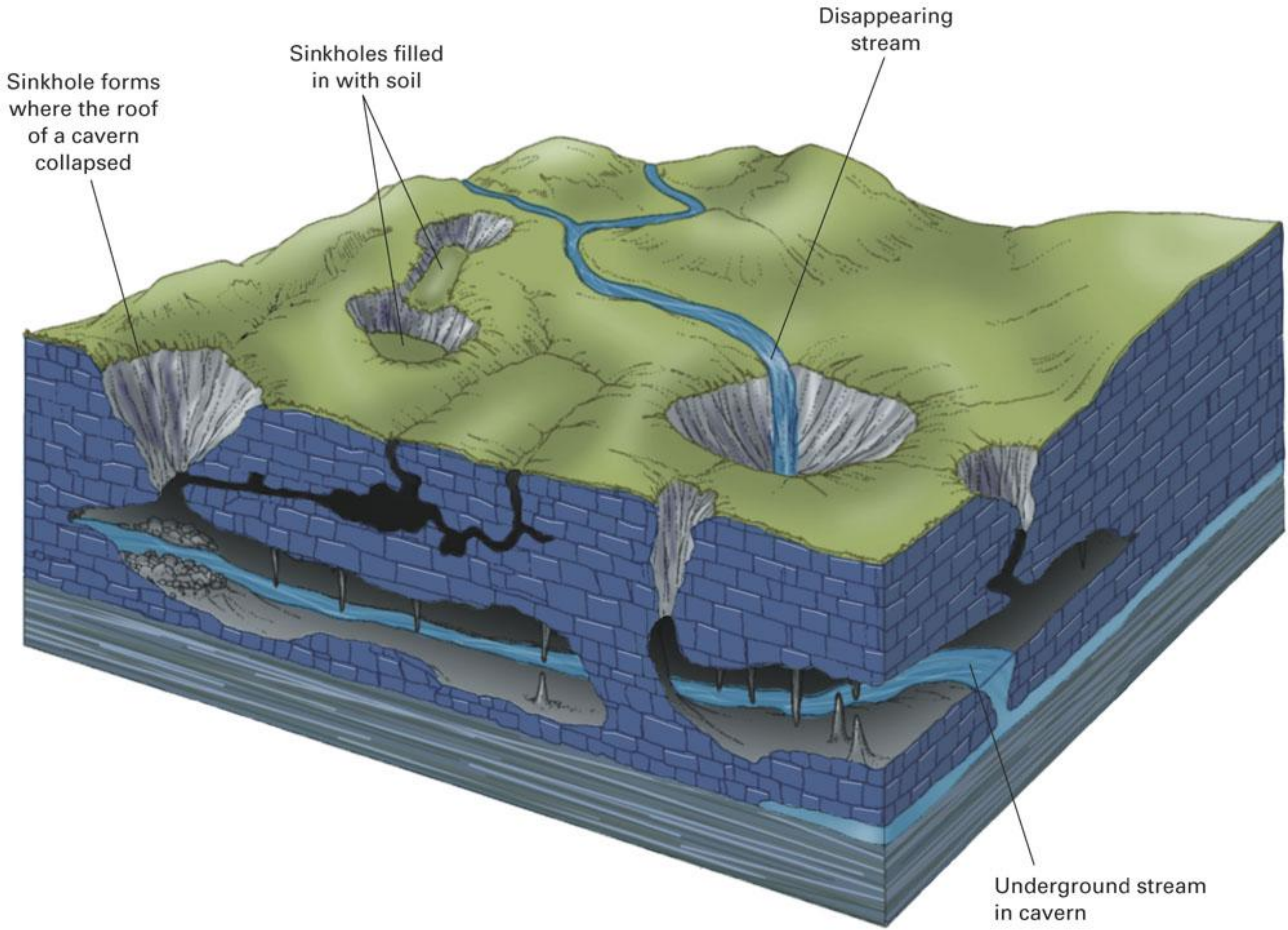
- Many areas of me world have landscapes that to a large extent have been shaped by the dissolving power of groundwater. Such areas are said to exhibit ***karst topography***.
- Karst areas typically have irregular terrain punctuated with many depressions, called ***sinkholes*** or ***sinks***.
- Sinkholes commonly form in *two* ways. Some develop gradually over many years without any physical disturbance to the rock. In these situations, the limestone immediately below the soil is dissolved by downward-sweeping rainwater.
- By contrast, sinkholes can also form abruptly and without warning when the roof a cavern collapses under its own weight. Typically, the depressions created in this manner are steep-sided and deep.
- karst regions characteristically show a striking lack of surface drainage (streams). Following a rainfall, the runoff is quickly funneled below ground through sinks. It then flows through caverns until it finally reaches the water table.

Stream Erosion by Abrasion



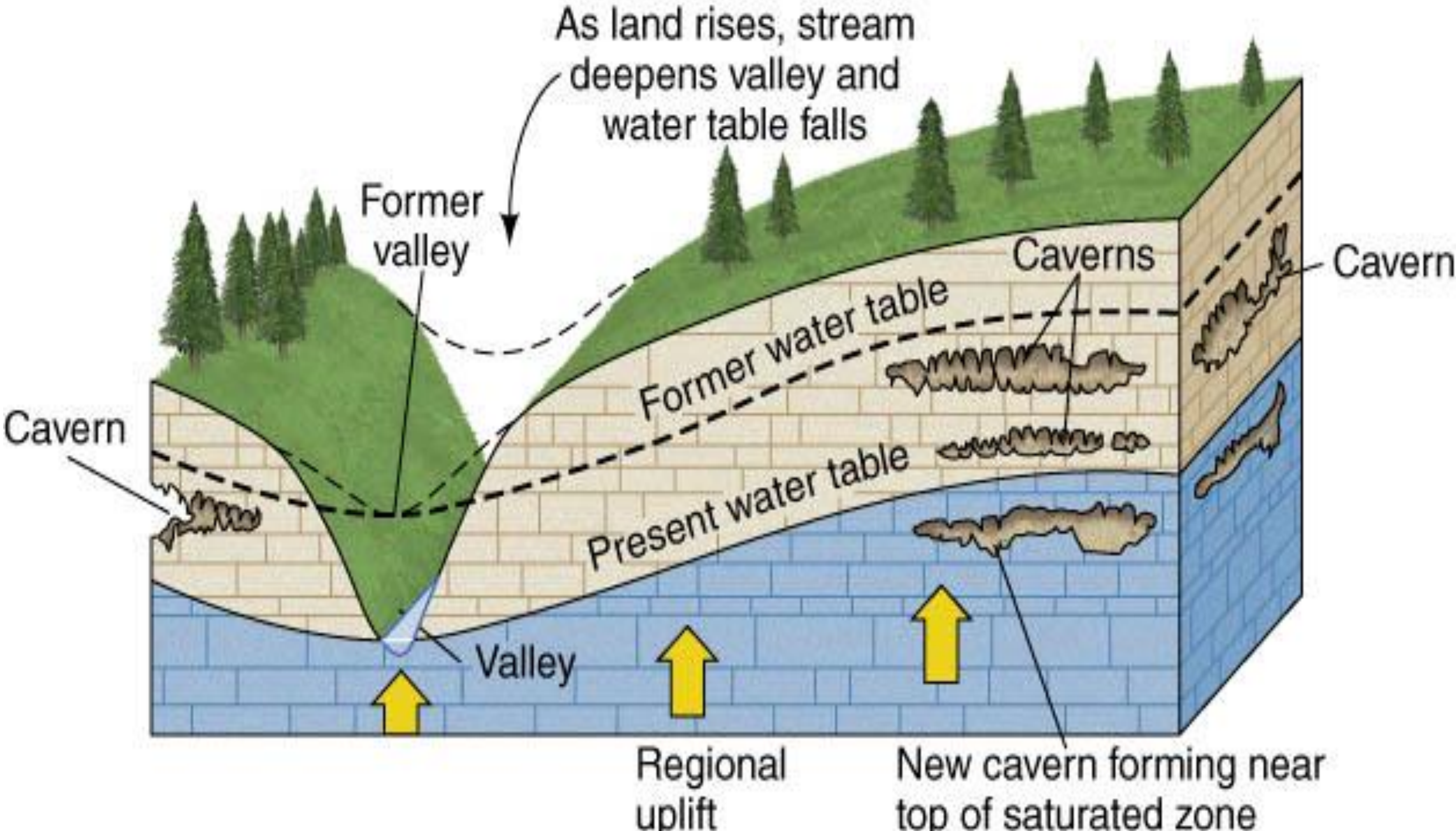
Potholes

Sinkholes in Limestone Mersa Matrouh, Egypt

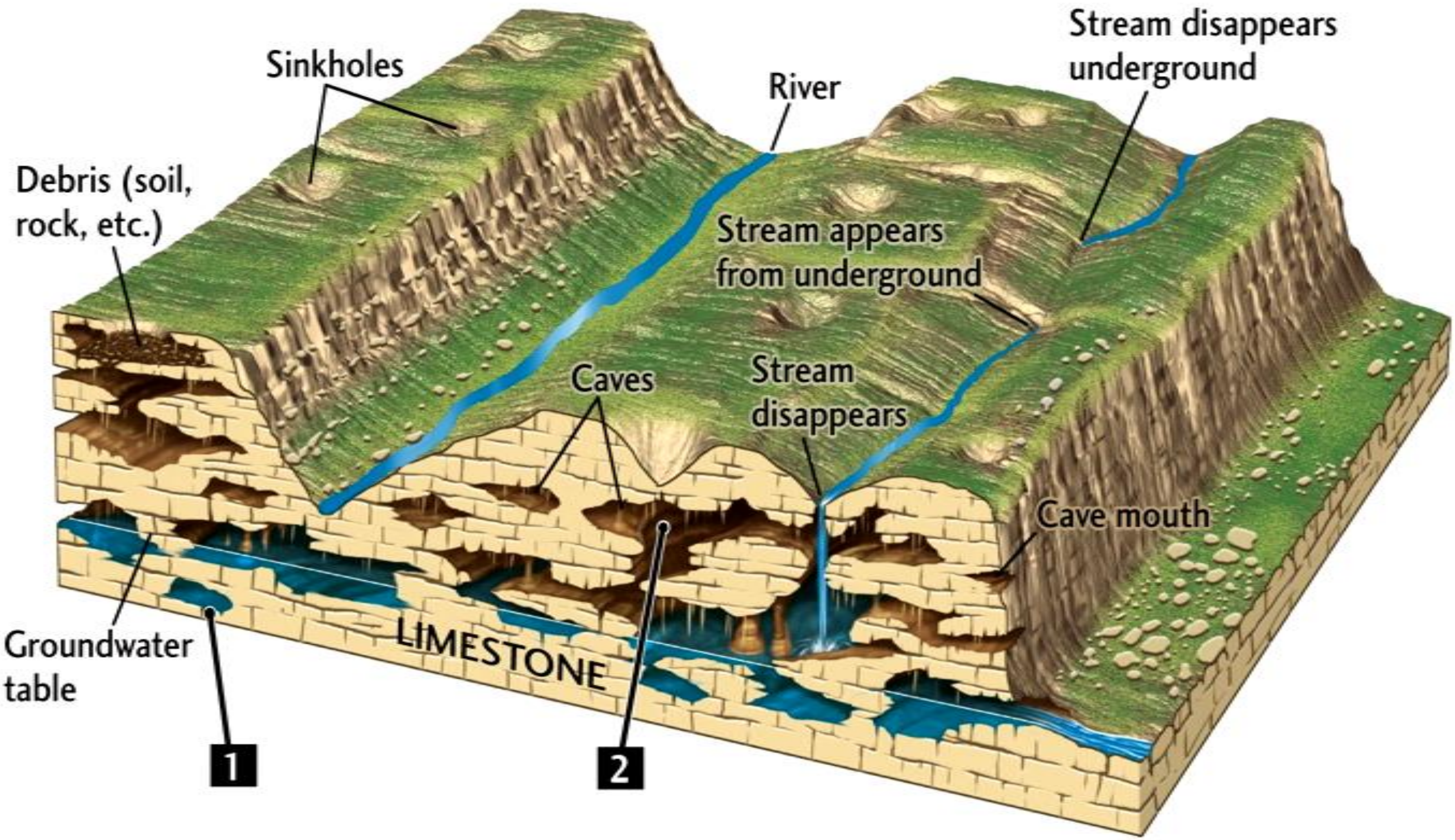


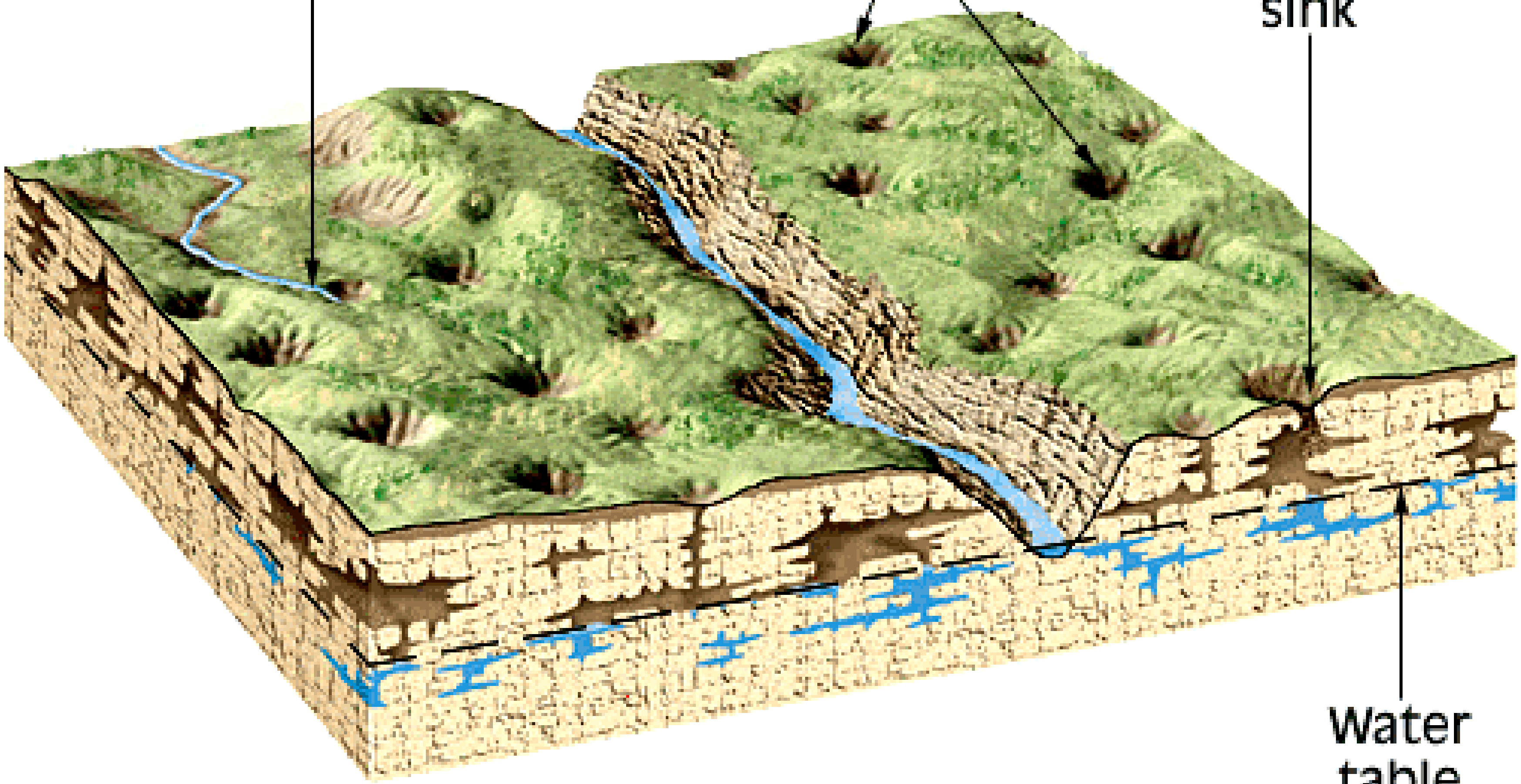
Sinkhole forms where the roof of a cavern collapsed
Sinkholes filled in with soil
Disappearing stream
Underground stream in cavern

Subsurface Features of a Karst Landscape



Subsurface Features of a Karst Landscape





Regions with many sinkholes exhibit *karst* topography.